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SECTION III.

OF ELECTRICITY.

CHAPTER I.

*Containing a general Idea of Electricity.**

124. IF a person, holding with one of his hands a clean and dry glass tube, rubs it with his other hand, which must also be clean and dry, by stroking it alternately upwards and downwards; and after a few strokes presents to it small light bits of paper, thread, metal, or of any other substance, the rubbed tube will immediately attract them, and after a short time will repel them. It will presently attract them again, then repel them, and so on; continuing this alternate attraction and repulsion for a considerable time.

If the glass tube be rubbed in the dark, and after having been stroked a few times, a finger be presented to it at the distance of about half an inch, a lucid spark will be seen between the finger and the tube, and this spark is accompanied with a snapping noise; the finger at the

* The most enlightened and inquisitive persons of the third or fourth century before the Christian æra, were acquainted with a remarkable property of, at least, two mineral bodies, one of which was *amber*, and the other was a hard stone, called *lyncurium* by Theophrastus (probably the same as is at present known under the name of *tourmalin.*) They knew that either of those bodies, and in particular the former, after a slight friction, would attract any kind of small bodies, such as bits of straw, ashes, &c. that might be presented to it within a certain distance.

They knew likewise that another mineral, which they called *magnet*, would attract iron, and all such bodies as contained a sufficient quantity of that metal. But a wide difference obviously existed between the power of the magnet, and that of the other above-mentioned bodies. The magnet attracted iron only, and its attractive property required no previous friction; the other bodies

same time receiving a push, as if it were from air issuing with violence out of a small pipe.

In this experiment, the attraction, repulsion, sparkling, &c. are the effects of that unknown cause, which is called *Electricity;* and hence they are called *electrical appearances.* The glass tube itself is called the *electric*, and all those bodies which are capable of producing such effects after friction, are called *electrics;* and as the rubbing awakes, as it were, in them the power of producing such effects, they are therefore said to be excited by the rubbing. The hand, or any other body that rubs an electric, is called the *rubber;* and if, instead of the person rubbing the glass tube, a machine be contrived capable of exciting an electric, that mechanism is called an *electrical machine.*

125. Let an oblong piece of metal, such as a poker, a long metallic spoon, &c. be suspended in the air by means of a dry *silk* string, upwards of a foot long, from any convenient support, and let small light bodies, such as have been mentioned in the preceding experiment, be presented to its lower extremity, within about an inch of it; then having rubbed the dry glass tube as before, place it near the upper end of the suspended metallic body, and you will find that the lower end of that body will attract and repel the light bodies, also will give sparks, &c. exactly like the excited tube itself; which shows that the electric virtue passes through the metal from one end to the other.

If, instead of a metallic body you suspend in a similar manner a glass stick, or a long stick of sealing-wax, and repeat the experiment, you will find that the lower part

could not act without previous friction, but then they would attract bodies of every kind indiscriminately, provided they were sufficiently light.

In process of time it was found that several other bodies, such as precious stones, sulphur, glass, &c. possessed precisely the same attractive property, not as the magnet, but as the amber; therefore they were said to have the property of the amber, which, in the Greek language, was called ηλεκτρον, whence the word *electricity* has been derived, and hence those bodies were said to be possessed of *electricity*.

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of the suspended stick of glass or of sealing-wax, will neither attract the light bodies, nor give any sparks; which shows that the electric virtue will not pass through glass or through sealing-wax.

Now the above-mentioned metallic body, and all those bodies through which the electric virtue can pass, are called *conductors* of electricity. But the glass stick, the sealing-wax, and all those bodies through which the electric virtue cannot pass, are called *non-conductors*. A body resting entirely upon, or suspended by, non-conductors, is said to be *insulated*.

All the bodies we are acquainted with, may be divided into conductors and non-conductors of electricity; and as it has been found that the non-conductors may be excited by friction; whereas the conductors cannot be excited by friction; therefore *electrics* and *non-conductors* mean the same bodies;* and *conductors* have also been called *non-electrics*.

Those distinctions are, however, far from being accurately settled and determinate. For instance, we are not acquainted with any body which, strictly speaking, may be said to be a perfect electric or a perfect conductor; the electric virtue finding some resistance in going through the best conductors, and being partly transmitted through, or over the surface of, most, if not all the electrics. The less perfect conductor any substance is, the nearer it comes to the nature of an electric; and, on the other hand, the less perfect electrics come nearest to the nature of conductors. In fact, there are certain substances which may be actually excited by means of friction, and at the same time are pretty good conductors.

126. The following lists contain, in general, all the electrics and the conductors, disposed, as much as it is practicable, in the order of their perfection, beginning with the most perfect of each class.

ELECTRICS.

Glass and all vitrifications, even the metallic vitrifications—All precious stones, of which the most transparent are the best—Amber—Sulphur—All resinous substances—Wax—Silk—Cotton—Several dry and external animal substances, as feathers, wool, hair, &c.—Paper—White sugar, and sugar-candy—Air, and other

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* Electrics have also been called *electrics per se*. It must be observed, however, that certain substances, such as oils, certain powders, &c. which are non-conductors, are called electrics from analogy; for they cannot be submitted to friction.

permanently elastic fluids—Oils—Dry and complete oxydes of metallic substances.—The ashes of animal and vegetable substances—Dry vegetable substances—Most hard stones, of which the hardest are the best.*

CONDUCTORS.

Gold—Silver—Copper—Platina—Brass—Iron—Tin—Quicksilver—Lead—Semi-metals, more or less—Metallic ores, more or less—Charcoal, either of animal or of vegetable substances†—The fluids of an animal body—Water (especially salt water), and all fluids, excepting the aërial, and oils—The effluvia of flaming bodies—Congealed water, viz. ice or snow; but when cooled down to — 13° of Fahrenheit's thermometer, Mr. Achard of Berlin found that ice lost its conducting property, and became an electric—Most saline substances, of which the metallic salts are the best—Several earthy or stony substances—Smoke—The vapour of hot water.—Electricity pervades also such a vacuum, or absence of air as is caused by the best air-pump; but not the perfect absence of air, or the torricellian vacuum, formed by boiling the quicksilver in a barometer tube.‡

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* Almost all the above-mentioned substances, when heated beyond a certain degree, become conductors. Thus red-hot glass, melted rosin, &c. are conductors of electricity. (Hot air has been reckoned a conductor; but this is denied by Mr. Read. See his Summary View of Spontaneous Electricity, p. 8.) The focus of a burning lens, or concave reflector, is not a conductor. Sometimes glass of a hard quality is so bad an electric as to be almost a good conductor. It is remarkable that often the nature of the same pieces of glass is changed by time, and by use, so as to become good electrics, though at first they were almost conductors, and *vice versa*.

A glass vessel is excited best when the air in it is a little rarefied; but a glass vessel entirely or almost entirely exhausted of air, on being rubbed, shows no signs of electricity on its external surface, but the electric power appears within the vessel. A glass vessel with condensed air in its cavity, or full of some conducting substance, cannot be excited; yet a solid stick or lump of glass may be excited.

† Charcoal is very equivocal in its conducting power; for some pieces of it will hardly conduct at all, whilst others are very good conductors.

‡ In rarefied air the attraction of electricity is weakened, and the electric light becomes more diffused, but less dense, in proportion to the rarefaction; but, though in a very small degree, they are, however, visible even in the best vacuum that can be produced by the most efficacious air-pump, viz. when the air which remains in the receiver is about the thousandth part of the original quantity. All this seems natural; for, since the air is an electric, the more

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It needs hardly be observed, that compound bodies partake more of the nature of conductors or of electrics, according as a greater quantity of the former or of the latter enters into their composition. Thus green vegetables, fresh wood, &c. are conductors on account of the water which they contain. Hence it follows, that all electrics, previously to their being used as electrics, must be properly cleaned and dried.

Baked wood is a very good electric, but it soon loses that property by imbibing moisture from the air: hence, in order to preserve it in a non-conducting state, it should be varnished as soon as it comes out of the oven; and then again thoroughly dried in a warm place, or in the oven itself.

CHAPTER II.

Of the two Electricities.

127. IF the person who rubs the glass tube, as mentioned in the preceding chapter, be insulated, viz. be suspended by means of silk strings, or stands upon a cake of rosin, &c. and in that situation rubs the tube with his hand; after a few strokes it will be found that the person and the glass tube are both electrified; for if any light bodies be presented to any part of the person's body, they will be attracted and repelled in the same manner as they are by the tube. The insulated person will also give out sparks to another conductor that may be presented to any part of his body; but the electricity of the insulated person is different from the electricity of the tube, and the difference principally consists in the following three characteristic properties.

I. Whenever an insulated light body, as for instance, a small piece of cork suspended by a silk thread, has been

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accurately this electric is removed from a given space, the more effectually can the electric power pass through it; and hence it might be expected. that the electric power would pass freely through the perfect torricellian vacuum. But it seems to have been fully ascertained by Mr. Walsh and Mr. Morgan, that such a vacuum is not a conductor of electricity.

attracted by the tube, and afterwards repelled; that cork will not be attracted again by the excited tube, but will be repelled by it, provided the cork in this state of repulsion is not touched by any conducting body. The same thing takes place if an insulated light body, like the cork, &c. be attracted and repelled by the person's body, viz. it will continue to be repelled by it. But if the insulated cork, which is actually repelled by the tube, be brought near the person, a strong attraction will take place between the cork and the person; and in the same manner, if the other cork, which is repelled by the person, be brought within a certain distance of the tube, the former will be strongly attracted by the latter. Or if the two insulated corks, which are repelled, viz. one by the tube, and the other by the person's body, be brought within a certain distance of each other, they will attract, and will rush towards, each other.

The same thing may be observed in a more convincing manner, by re-presenting more than one light body to each of the electrified bodies. Thus let A, B, fig. 68., be two cork balls fastened by a linen thread ACB, and let the part CD be a silk thread fastened to a proper support, at some distance from the wall or other object. In this situation, if you bring the excited glass tube near the balls A, B, the tube will attract them, and will soon after repel them. Now let the tube be removed, and the cork balls will be found to repel each other, and to remain for a considerable time in the situation of fig. 69.

Let another similar pair of cork balls be brought in contact with the insulated person that has rubbed the tube, and these also will afterwards repel each other, as in fig. 69. But if those two pairs of repellant cork balls be brought near, they will attract each other, and by their mutual contact the electrical virtue (viz. the attractive and repulsive powers) will be quite annihilated: which shows, that one of those electricities is quite the reverse of the other, the one seeming to have what the other wants.

Pairs of cork balls similar to those of fig. 68., are generally used for manifesting when a body is electrified or not; for if the suspected body be brought into contact with the balls, and then be removed, the balls will immediately diverge, if the body had any electricity to communicate, but not otherwise. Hence a pair of such balls is called an *electrometer*, or an *electroscope*.

II. The second difference between the two electricities, consists in the appearance of their light. If a pointed, but un-insulated, conducting body, as a pin, a needle, or

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the like, be presented to the excited tube in the dark, a lucid globule, or star, will be seen upon its point; but if this pointed body be presented to the insulated person, especially while he is actually rubbing the tube, then, instead of the star, a lucid pencil of rays will appear to proceed from the point.

III. Lastly, it will appear from some experiments which will be described hereafter, that when one body A is possessed of the electricity of the tube, and another body B is possessed of the electricity of the person, the electric power, in its passage from one of those bodies to the other, (which annihilates the electricities) manifests an evident current from A to B, but not from B to A.

128. If the insulated person rub, not a glass tube, but a stick of sulphur; both the man and the sulphur will be electrified with the two different electricities: but in this case the sulphur acquires the electricity which, in the preceding experiment, was acquired by the insulated man; and the insulated man will acquire the electricity which was acquired by the glass tube; for in the latter experiment the needle presented to the sulphur will show a pencil of light, and that which is presented to the man that has rubbed the sulphur, will show a lucid star.*

The two electricities always accompany each other; for whenever any two bodies (being both insulated, or only that which is a conductor) are rubbed against each other, if any one of them acquire any electricity, then the other body will certainly acquire the other electricity.

Almost all the electrics may be made to acquire, at pleasure, the one or the other of the two electricities; viz. by using particular rubbers. Thus, if a glass tube be drawn across the back of a cat, it will acquire the resinous electricity; but if rubbed with any other substance, it will then acquire the vitreous electricity. Thus also

* As the contrary nature of those two electricities was originally observed by rubbing glass and sulphur; therefore, one of them, viz. that which produces a star upon the pointed body that is presented, was called the *vitreous electricity*, as it was imagined to be produced by rubbed glass in all cases; and the other, viz. that which produces the luminous pencil upon the pointed body that is presented, was called the *resinous electricity*.

a stick of sealing-wax will acquire the vitreous electricity, when rubbed with any metallic substance; but it will acquire the resinous electricity when rubbed with leather, or paper, or the human hand, &c.

A slight alteration, either of temperature, or of surface, or of pressure, will dispose a body to acquire one electricity rather than the other; the rubber always acquiring the opposite electricity.

129. When the difference between the two electricities was first observed, it was imagined that the two powers were both owing to emanations of two particular elastic fluids, which, when mixed in due proportion, would counteract each other, or would form a sort of neutral compound. But a supposition much simpler, which goes under the name of the Franklinian theory, and which is peculiarly corroborated by the above-mentioned third difference between the two electricities, viz. that of the current from the vitreous to the resinous electricity, is as follows:

All the phenomena, called electrical, are supposed to be produced by an invisible and subtile fluid existing in all the bodies of the terraqueous globe. It is also supposed that this fluid is very elastic, viz. repulsive of its own particles, but attractive of the particles of other matter.

When a body does not show any electrical appearances, it is then supposed to contain its natural quantity of this electric fluid; (but whether that quantity bears any proportion to the quantity of matter, or not, is utterly unknown) therefore, that body is said to be in its *natural*, or *non-electrified state:* but if a body shows any electrical appearances, it is then said to be *electrified*, and it is supposed that it has either acquired an additional quantity of electric fluid, or that it has lost some of its natural share. And from the above-mentioned circumstance of the current, &c. (Art. 127. III.) we are led to suppose, that the vitreous electricity arises from an over-charge of that fluid, and that the resinous electricity arises from an under charge, or diminution of the natural quantity of that fluid. Hence the vitreous electricity has also been called the *plus*, or the *positive electricity;* and the resinous has been called the *minus*, or the *negative electricity.**

* The other numerous hypotheses, that have been offered in ex-

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This theory shows, that when an electric and a conducting substance are rubbed against each other, the electric fluid is not generated; but, by the action of rubbing, one body pumps, as it were, the electric fluid from the other body. Hence, if one body becomes overcharged with it, or electrified positively, the other must become undercharged, or electrified negatively, unless its deficiency be supplied by other bodies that communicate with it.* Hence also, we see the reason why, when an electric is rubbed with another electric, or with an insulated rubber, it can acquire but little electricity, viz. because in that case the rubber cannot be supplied with electric fluid from other bodies.

Electric attraction is easily explained; for this does not exist, except between bodies that are differently electrified, where the superfluous electric fluid of the bodies that are electrified positively attracts, according to the theory, the undercharged matter of those which are electrified negatively.†

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planation of the electrical phenomena, are too deficient to deserve any particular notice.

* By what mechanism one body extracts the electric fluid from another body during the rubbing, is by no means known. The increased capacity of the electric for the electric fluid in certain situations, seems to afford a plausible explanation. The nature of those capacities will be explained hereafter.

† The application of this theory to the other phenomena of electricity we shall subjoin to the description of the experiments which will be given in the course of this Section.

CHAPTER III.

Of communicated Electricity, particularly to Conductors.

130. WHENEVER any electricity is communicated to a body, be it positive or negative, it is confined upon it only by electrics, and will remain with that body a longer or a shorter time, according as the electrics which confine it are more or less perfect. Thus the electricity which is superinduced upon a glass tube by rubbing it, remains upon the tube, insomuch as it is surrounded by the air, which is an electric; and as the air is in a more or less perfect electric state on account of its moisture, dryness, &c. so the electric virtue is retained upon the glass for a longer or a shorter period; and sometimes an excited glass tube will remain sensibly electrified for upwards of twenty hours.

If a finger, or any other conductor, be presented to an excited electric, it will receive a spark, and in that spark a certain portion only of the electricity of the excited electric, because that electric cannot convey the electricity of all its surface to that part to which the conductor has been presented. Hence, if a conductor be presented successively to different parts of the excited electric, it will receive a spark at every approach, until all the power of that electric is exhausted, and then a new excitation is necessary in order to revive it.

Whenever a conductor, which communicates with the earth, (viz. not insulated) is presented at a convenient distance to an excited electric, it acquires, on that presented side, an electricity contrary to that which is possessed by the electric. This electricity increases as the body is approached, and at last, there being an eager attraction between positive and negative electricities, the conductor receives a spark from the electric, by which means the balance is restored.

If the conductor do not communicate with the earth, but be insulated, then on being presented, as before, to

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the excited electric, not only that side of it which is towards the electric, but the opposite side also will appear electrified; with this difference, however, that the side, which is exposed to the influence of the electric, has acquired an electricity contrary to that of the excited electric, and the opposite side has acquired the same electricity as that of the electric. Those two different electricities of the conductor increase as the conductor comes nearer to the electric, and at last it receives a spark from the electric, and becomes throughout possessed of the same electricity with the electric.

All those effects will take place in the same manner, if a thin plate of glass, or of rosin, or of other electric substance, be interposed between the conductor and the excited electric; but then a spark cannot come from the electric to the conductor, unless it opens its way by bursting the interposed electric, as it always does in passing through the air. This displacing and subsequent collapsing of the air is what causes the noise that attends a spark.

An insulated conductor that has received the electricity from an excited electric (in which state it is said to be *electrified by communication*) will act in every respect like the excited electric itself, excepting that when it is touched by another conductor which is not insulated, the former will give one spark to the latter, discharging at once all its electricity; because the electricity which belongs to every part of its surface is easily conducted through its substance to that side to which the other conductor is presented.* Hence it follows, that the electricity, which is discharged by an electrified and insulated conductor, is in general stronger than that which is discharged by an excited electric.

131. If there be two insulated conductors, one of which only is electrified, and if this conductor be touched by the other, then the electricity will be divided amongst those conductors; but it will be divided neither equally nor in proportion to their quantities of matter. But if the conductors be quite alike, and be similarly situated with respect to the surrounding bodies; then the electricity will be divided equally among them. If their surfaces be equal but dissimilar, as for instance, a square foot of tin foil in one piece, and another square foot of the same cut into a long slip; then the latter, viz. the body whose surface has a greater extension, will acquire more electricity than the other. If, when the two conductors are equal and similar, one of them lies contiguous to an imperfect conductor, and the other is contiguous to the air only; then the former will acquire a greater quantity of electricity than the latter.

The electric spark (viz. a separate quantity of electricity) will go a greater or less distance through the air, in order to reach a conductor, according as its quantity is greater or less; as the parts from which it proceeds, and on which it strikes, are sharper or more blunt, and as the conductor is more or less perfect.

The noise and the light which accompany the spark, are greater or less according to the quantity of electricity, also as the parts from which it proceeds, and on which it strikes, are blunter or sharper, and as the conductor is more or less perfect. Thus a sharp-pointed body will throw off electricity to, and receive it from a greater distance than a body of any other shape; but that passage occasions no remarkable noise, and is attended with little light; for in this case the electricity comes not in a separate large body, but by little and little, or rather in a continuate stream.

* It must be observed, however, that when the electrified conductor is large, and much extended, a very trifling residuum of electricity generally remains upon it, which will afford a second, but incomparably smaller, spark.

132. If a pointed wire be concealed in an open glass tube that projects a short way beyond the point, or if it be covered with tallow, or bees-wax, or sulphur, &c. then it will take a strong spark from an electrified conductor.

It is remarkable, that when points are throwing off, or are receiving electricity, a current of air always appears to proceed from the point, and that is the case whether the electricity is positive or negative.

A pretty large quantity of electricity pervades the substance of a conductor of considerable length with surprising and inappreciable velocity; but a small quantity of it has been found to take a little time in passing through a long and less perfect conductor.

The electric spark taken upon any part of a living animal body, causes a disagreeable sensation, which is more or less so, according as the spark is stronger or weaker, and as the part is more or less delicate, or the person more or less sensible.

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133. It has been repeatedly asserted and denied, first, that electricity communicated to insulated animal bodies, quickens their pulse, and increases their perspiration; 2dly, that if it be communicated to insulated fruits, fluids, and other bodies which are actually in state of evaporation, it increases that evaporation; and, 3dly, that it promotes vegetation.

With respect to the first circumstance, the most accurate experiments show that electrization, whether by positive or negative electricity, does not accelerate nor retard the ordinary number of pulsations in a sound person; but that the quickening of the pulsation, which is often observed in such cases, arises from fear or apprehension.*

The perspiration of animal bodies, fruit, and other substances that are actually in a state of evaporation, is increased but little by electrization; provided those substances are exposed to the ambient air with a free surface.

With respect to vegetation, the most impartial, diversified, and conclusive experiments have shown, that electrization does neither promote nor retard vegetable life.

134. If the face, or any part of the body, be presented to an excited electric, or to a conductor strongly electrified, a sensation will be felt as if a wind were blowing, or rather as if a spider's web were drawn over it.

If the nostrils be presented to an excited electric, a smell will be perceived which much resembles that of phosphorus; but communicated electricity does not occasion any such sensation, except when a large quantity of it passes suddenly from one body to another.

If the stream of electricity which issues from an electrified point be directed on the tongue, a peculiar taste is perceived; and bodies that have been a certain time exposed to that stream, or to strong electric effluvia in general, retain a certain smell, such as has been mentioned above, for a considerable time after.

135. If electricity be communicated to an insulated vessel containing water, and the water be actually running out of it through a hole or pipe; the stream, if less than a tenth of an inch in diameter, will be accelerated, and more so in proportion as its diameter is smaller; it will even drive the water in a continuate stream out of

* See my Treatise on Elect. 4th edition, vol. III. p. 277.

a very small capillary tube, out of which, without the aid of electricity, the water will not even be able to drop. When above a tenth of an inch in diameter, the stream, though it divides and carries the fluid further, is, however, neither sensibly accelerated nor retarded by electricity.

136. Towards the beginning of this chapter it has been said, that when a conductor is presented to an electrified body, it acquired, on the presented side, an electricity contrary to that of the electrified body. We must now add a very remarkable law, viz. that no electricity can be observed upon the surface of any electrified body, unless that surface is contiguous to an electric, which can in some manner or other acquire the contrary electricity at a little distance; or, in other words, no electricity can appear upon the surface of any electrified body, unless that surface is opposite to another body which has actually acquired the contrary electricity; and those contrarily electrified bodies must be separated by an electric. Thus, when an insulated body, which stands at a distance from other conductors, is electrified, the air which surrounds it performs at once the office of an electric and of a conductor; for it acquires the contrary electricity at a little distance from the electrified body, whilst the intervening stratum of air separates those two electricities.

137. With respect to the passage of electricity from one body to another, we may in general remark, that if the repulsion existing between bodies that are possessed of the same kind of electricity be excepted, all the other electrical phenomena are produced by the passage of electricity from one body to another.

With respect to attraction and repulsion, this general law must be remembered, that those bodies, which are possessed of the same sort of electricity, repel, or tend to repel, each other; but bodies, which are possessed of different electricities, attract, or tend to attract, each other; and there is no electric attraction but between bodies which are possessed of different electricities.

This last assertion may at first sight appear to be contradicted by the effect which takes place when small bodies are presented to an excited tube, or to any other electrified body; for they are attracted by it, though they have not been previously exposed to any electrization; but the difficulty will vanish, if it be recollected, that the small bodies naturally acquire the contrary electricity merely by their being brought within the sphere of action of an electrified body; so that when they are attracted, they are actually possessed of the contrary electricity.

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CHAPTER IV.

Of Electricity communicated to Electrics, and of the Leyden Phial.

138. THE electric virtue may also be communicated to electrics; but this communication to electrics is attended with several circumstances, different from those which attend the communication of electricity to conductors; for when one side of any of the latter receives some electricity, that electricity instantly pervades its whole substance; whereas when an electric is presented to an electrified body, a spark from the latter will electrify the former in a small spot only; for, on account of its non-conducting quality, the electricity cannot expand itself through it. In short, when an electric is presented to an electrified body, the former will acquire different electricities on different sides, (as has been said of conductors in the preceding chapter); these electricities increase according as the distance between the two bodies diminishes, viz. as they are brought nearer; but if at last a small quantity of electricity be communicated to one part of the electric, that electric will not become throughout possessed of one electricity, but will, in some cases, still show different electricities on different sides; and in certain circumstances, many repeated changes from positive to negative electricity may be observed upon the very same electric.

139. If to one side of an electric sufficiently thin, such as a pane of common window glass, a plate of sealing wax, &c. you communicate one electricity, and to the opposite side you communicate the contrary electricity, that plate in that state is said to be *charged*, and the two electricities cannot come together, and annihilate each other, unless a communication by means of conducting substances be made between both sides, or the electric plate be broken by the force of electric attraction.

When the two electricities of a charged electric are by any means united, and of course their powers destroyed, then that electric is said to be discharged; and the act of union of those two opposite powers is generally called the *electric shock;* because when a living animal body forms the circle of communication between the two sides of the charged plate, the discharge which must pass through it, occasions a sudden motion, by contracting the muscles through which it passes, and gives a peculiar sensation.

In order to avoid the difficulty of communicating electricity to an electric plate, it is customary to coat the sides of it with some conducting substance, such as tin-foil, gold-leaf, sheet-lead, &c. by which means the charging and discharging becomes very easy; for when the electricity is communicated to one part of the coating, it immediately spreads itself through all the parts of the electric that are in contact with that coating; and when the electric is to be discharged, it will be sufficient to make a conducting communication between the coatings of both sides.

Those coatings must not come very near to each other towards the edge of the plate, for in that case a communication between those coatings is ready at hand; and though the coatings are not absolutely in contact, yet when they are electrified, the electricity will easily force a passage through the air, and, by passing over the surface of the electric plate from one coating to the other, renders it incapable of receiving any considerable charge.*

140. If a glass plate (and the same thing must be understood of other electric substances), whether smooth or rough, be coated with some conducting substance, so that the coatings do not come very near the edge of the plate; and if some electricity be communicated to one of these coatings, whilst the other coating communicates with the earth, or with a sufficient quantity of conducting bodies; then the last mentioned coating will of itself acquire about an equal quantity of the contrary electricity; otherwise the glass plate cannot be charged, except in a very trifling degree.

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* The property of conducting the electricity over their surface is so great in some kinds of glass, as to render them quite unfit for the purpose of charging and discharging.

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Now the reason why, when one side of the glass is receiving one electricity, the opposite side acquires the other electricity, is the same as was mentioned above, viz. the property which bodies have of acquiring an electricity contrary to that which is possessed by a contiguous electrified body; and the interposition of the glass plate keeps those electricities separate: but if the charge be too high, and the glass plate too thin, then the great attraction between the two different electricities forces a passage through the glass, discharges it, and, by breaking it, renders it unfit to receive another charge.*

141. This remarkable property was discovered by Von Kleist in 1745,† but it was first satisfactorily noticed at Leyden, where the experiment was performed with a phial; hence a phial or bottle coated on the inside and outside for the purpose of charging, &c. has been called the *Leyden Phial*, otherwise an *electric jar;* and the charging and discharging of a coated electric, in general, has been called the *Leyden experiment.*

A coated glass is capable of holding a greater charge in condensed than in rarefied air, provided the air be dry.

If a coated glass plate or jar, after having been charged, be insulated, and only one of its coatings, or sides, be touched with some conductor, that side will not part with its electricity, because the electricity of one side exists in consequence of the contrary electricity on the opposite side, and they, by their mutual attraction, confine each other on the surface of the glass. Therefore, in order to discharge that glass, both coatings must be connected by means of a conducting body, and then the discharge is made through that conductor.

* Those effects take place in the same manner if the glass be not in the form of a plate, but in any other shape whatsoever, provided it be sufficiently thin; for the thinner the glass is, the higher charge it receives; but then it is more liable to be broken by it.

† Priestley's Hist. of Elect. 3d edit. vol. I. p. 102.

The discharge may also be made by connecting each coating with a large quantity of conducting bodies.

When, in order to discharge a jar, one of its coatings is touched first with a conductor, as for instance, with one end of a brass chain, no particular phenomenon will take place; but as soon as the other end of the chain comes within a sufficient distance of the other coating, a spark will be seen between this end of the chain and that coating, accompanied with a report, and the jar is instantly discharged.

The spark thus produced by the discharge of a charged electric, or Leyden phial, is much brighter, much louder, but at the same time much shorter than that which is taken from an insulated conductor that contains an equal quantity of electricity.

If the communication between the two coatings of a charged jar be made by means of imperfect conductors, as a slender piece of wood, or wet pack-thread, &c. the discharge will be made silently, but not so suddenly, and of course its effects will not be so great, as when it is discharged suddenly.

The force of the shock, which is produced by coated glass of a given thickness, is proportionate to the quantity of coated surface, supposing that the charge has been carried up to the utmost degree. Hence, by increasing the quantity of coated surface, the charge, and the effects of the discharge or shock, may be increased almost to any degree. A number of coated jars, connected together in such a manner as to unite their forces and act like one jar, constitutes what is called an *electrical battery.*

In making the discharge, the electricity, which goes from one side of the jar to compensate the contrary electricity of the opposite side, through good conductors, has been found to move with inappreciable quickness.

The force and the noise of an electric discharge is not affected by the inflections of the conductor through which it passes, but is sensibly weakened by its length.

It evidently appears that the electricity finds some obstruction in going through even the best conductors; for in some cases it will prefer a short passage through the air, to a long one through the best conductors. The obstruction is greater where the conductors, which form the circuit, are not in perfect contact, and especially where the electricity must pass from a more perfect to a less perfect conductor.

142. A strong shock sent through an animal or a plant, puts an end to animal as well as to vegetable life.*

* The common *Balsam* is the plant which seems to be killed

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If a small interruption of the circuit be made in water, on making the discharge (notwithstanding that the water is a conductor) a spark will be seen in it, which never fails to agitate the water, and often breaks the vessel that contains it. If, by making a small interruption of the circuit between the two sides of a Leyden phial, in water, the shock is passed through it, so as to produce a spark in the water, that discharge will be found to produce an exceedingly small bubble of elastic fluid; and, by repeating the discharge a vast number of times, a certain quantity of that elastic fluid may be accumulated, which is inflammable, and appears to be a mixture of hydrogen and common air or oxygen air, viz. the components of water. By inflammation this elastic fluid explodes, and is converted again into water.

If the circuit be interrupted by one or more electrics, or imperfect conductors, of a moderate thickness, the electric shock will break them, and in some circumstances will disperse them in every direction, as if the force proceeded from the centre of every one of the interposed bodies. In several instances the effect of the shock upon an interposed body is evidently greater on that side of it which communicates with the positive side of the jar or battery.

A strong shock sent through a slender wire, or a small piece of metal, makes it instantly red-hot, melts it, and, when the fusion is perfect, reduces it into globules of different sizes, or even into a scoria.* If the metal be placed between pieces of glass, the shock, by

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easiest by electricity. The shock of a small jar, such as a coated 4 ounce phial, is sufficient to destroy the life of a full grown balsam. The plant begins to droop immediately after the shock.

* The force which is required to melt wires of the same metal, must be greater or less, according to the length and thickness of the wire; but it is far from bearing any direct proportion to the quantity of metal; for if a wire of a certain length and diameter be barely melted by a large battery, a wire of equal length and twice the substance, cannot perhaps be melted by less than ten such batteries.

melting it, will force it into the very substance of the glass. The glasses themselves are generally shattered to pieces.

If those glasses which inclose the metal be pressed by heavy weights, then a remarkably small shock is often capable, not only of shaking off the weights, but also of breaking such thick glasses as otherwise would require the force of a large battery. A thick piece of glass may likewise be broken into innumerable fragments, by only sending a shock over a small part of its surface, when that part is pressed by weights, without the interposition of any metal. When such pieces of glass are not broken by the explosion, they then will frequently be found marked with the most lively prismatic colours, which lie sometimes confused, and at other times in their prismatic order. The coloured spot is evidently owing to thin plates or scales, (73) partly separated from the glass; and it generally occupies a space of about one inch in length, and half an inch in breadth.

143. When a moderate shock (meaning a shock that is not sufficient to melt the metallic circuit) is sent through an imperfect metal, especially when the circuit consists of several pieces, as a chain; a black dust, in the form of smoke, will proceed from that metal, which is a metallic oxide. If such circuit be laid upon paper, glass, or other non-conductor, this, after the explosion, will be found stained with indelible marks, and often shows evident signs of having been burnt. A long and permanent track may be marked upon glass, and upon several other bodies, especially upon certain painted surfaces, by passing an electric shock over their surfaces.

A shock sent through several metallic oxides, when these form part of the circuit, frequently reduces them into the metallic state.

144. A sufficiently strong shock sent through a magnet has sometimes destroyed its virtue, and at other times has invigorated it, or even reversed its poles. The following particulars will show the circumstances that are likely to produce such effects. When the charge of eight feet of coated glass surface, or even less, is sent through a fine sewing-needle, the needle will thereby often acquire a magnetic polarity, so as to traverse when

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laid gently upon the water. If the needle be struck, lying east and west, then that end of it which is entered by the shock, viz. that which communicates with the positive side of the battery or jar, will afterwards point north; but if the needle be struck laying north and south, then that end of it which stands towards the north will, in any case, point north, and the needle will acquire a stronger virtue in this than in the former case; and lastly, if the needle be set straight up, and the electric shock enters it at either point; then the lower extremity of the needle will acquire the property of pointing north.* This however cannot take place in all parts of the world, for a reason which will appear in the next section.

145. A small shock is sufficient to inflame several inflammable substances; and inflammable spirits may be fired even by a spark proceeding from an electrified conductor.

If the moderate charge of a large battery be discharged between two smooth surfaces of metallic bodies, lying at a small distance from each other; or if the explosion of a battery, issuing from a pointed body, as the point of a needle, be repeatedly taken upon the smooth and plane surface of a metallic body, situated at a little distance from the point; in either case the metallic surface or surfaces will be found marked with circles of partly scaled or fused metal round a central spot, and, especially in the latter case, they will frequently exhibit all the prismatic colours.†

146. When the discharge of a battery is made by bringing the conductors which proceed from the coatings of a battery, in contact with, or at a little distance from, the surface of certain conducting substances, as water, raw meat, moist wood, &c. the electricity, instead of going through those substances, will go over their

* See Franklin's Letters, p. 90.

† For further particulars concerning those circles, see the Phil. Trans. vol. 58.

surface in a luminous track; sometimes preferring a much longer passage over the surface to a short one through the substance. In this case the explosion never fails to give a concussion to the body over which it passes.

The electric explosions taken upon the leaves of delicate flowers frequently change their colours.

The colour of the electric spark, when taken in hydrogen or in ammoniac gas, is purple; in carbonic acid gas, it appears white.

The electric spark taken repeatedly in common air, diminishes a little its purity. In other permanently elastic fluids sometimes it increases, and in others it diminishes, their bulk, and alters their quality in a certain degree.*

By making the electric discharge a great many times in a mixture of oxygen and common air, or of oxygen air and azotic gas, the nitrous acid is produced.†

147. According to the theory, the electric fluid which is communicated to one side of the glass drives away the electric fluid from the other side, or the electricity of one side induces a contrary electricity on the opposite side; but it is impossible to say how this virtue or this repulsion can operate through the glass, which is impervious to the electric fluid; much less do we know where the superinduced electric fluid resides.—Is it lodged in the surface of the glass, or in the air contiguous to the glass? In the first case, if the additional electric fluid penetrates a certain way into the substance of the glass, it follows, that a plate may be given so thin as to be permeable to the electric fluid, and of course incapable of a charge; yet glass balls blown exceedingly thin, viz. about the 600th part of an inch thick, when coated, &c. were found capable of holding a charge.‡

Mr. Canton charged some thin glass balls about 1½ inch in diameter, having necks or tubes of about nine inches in length, and afterwards sealed the ends of the tubes hermetically. If those balls were presented to an electrometer, they showed no sign of electricity; but if they were warmed, by being kept a short time before the fire, then they appeared to be strongly electrical, and appeared possessed of that electricity which had been communicated to their inside; which shows that heat renders the glass permeable to the

* See Dr. Priestley's second vol. of Observations on different kinds of air; and Dr. Van Marum's Account of Experiments with the Teylerian Elec. Machine at Harlem.

† See Mr. Cavendish's Experiments, which produced this remarkable discovery, in the Phil. Trans. vol. 75 and 78.

‡ The charging of a jar does by no means displace the air from its inside; neither does the charge heat or cool it.

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electric fluid. This electricity is not that which properly constitutes the charge, but is the superfluous electricity of their inside; for an electric jar may always retain a little more electricity on one side, than what is just sufficient to counteract the electricity of the opposite side. If a charged jar be insulated, and then be discharged by connecting its coatings with an insulated discharging rod, after the discharge, both the sides of the glass together with the discharging rod, will be found slightly possessed of the electricity contrary to that of that side of the jar which was touched last.

148. Some very remarkable phenomena, the cause of which is far from being clearly understood, are exhibited by flat glass plates, jointly charged like a single plate. If two flat glass plates be placed one upon the other, and their outward surfaces be coated with tin-foil, in the usual manner of coating a single plate for the Leyden experiment; and if these be charged by presenting one coating to an electrified body, and communicating the other with the earth; the plates (which we shall call A and B) after the charge will adhere firmly to each other; but if separated, A, whose coating was charged positively, will appear positive on both sides, and B negative on both sides. If these plates be laid one upon the other as before, and be discharged, by making a communication between the two coated sides, they will afterwards be found still to adhere to each other, and if separated, they will still appear to be electrified, but with this remarkable difference, viz. that A is negative on both sides, and B positive on both sides. If, after the discharge, the separation be made in the dark, flashes of light will be perceived between their internal surfaces. By laying the plates together, touching their coatings, and separating them successively, the flashes may be observed for a considerable number of times, diminishing by degrees until they vanish.

But those effects are not constantly the same with all sorts of glass. Crown-glass and common plate glass exhibit the above-mentioned phenomena; but it was observed by Mr. Henly, that Dutch glass plates, when treated in the same manner, have each a positive and a negative side. He also observed some other irregularities. Beccaria endeavoured to account for those and similar phenomena by supposing that when two bodies, either a conductor and an electric; or two contrarily and equally electrified electrics, are put

one upon the other, they adhere to each other, and their electricities disappear, because the two opposite powers counteract each other; but as soon as they are separated, the electrics show a power or a tendency to recover their electricities. This is what he called *vindicating electricity*.*

149. We shall lastly observe, with respect to communicated electricity, that the application of it either as simple electrization, or in the form of sparks and shocks to the human body, has been found unquestionably serviceable in various disorders, some of which had resisted every other medical application. But it must at the same time be confessed that this application is not frequently successful to any remarkable degree.

Without entering into any particular discussion respecting its power, or the particular effects which are attributed to it in particular disorders, I shall in general observe, that the application of electricity has mostly proved beneficial in recent cases of obstruction, whether of motion, of circulation, or of secretion; and that a gentle application has, upon the whole, proved more advantageous than strong shocks.

The most general practice is to insulate the patient, to place him in contact with the electrified conductor, in the manner which will be shown hereafter, and then either to present a pointed body towards the part affected, (which produces rather an agreeable sensation, and is called *giving the electrical aura*); or to draw sparks from the part, or at most to pass very slight shocks through it.†

* For further particulars relative to this vindicating electricity, see Beccaria's Art. Elec. Part. II. Sec. VI. or my Treatise on Elec. 4th edition, vol. II. Appendix No. I.

† A novice in this branch of natural philosophy will hardly understand the meaning of several facts that are mentioned in this and the preceding chapters of this section. They have been put together for the sake of reference, and in order that the leading principles of the theory might be seen under one point of view; but the experiments which will be described in the sequel will probably remove every difficulty.

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CHAPTER V.

Description of the Electrical Apparatus.

150. THE electrical apparatus consists of instruments necessary either for producing electricity, or for accumulating, retaining, and employing it; or lastly, for measuring its quantity and ascertaining its quality.

The principal instrument for the production of electricity is a machine capable, by any means, of exciting an electric, so as to produce electrical appearances. The most essential parts of this machine are the electric, the moving engine, the rubber, and the prime conductor, viz. an insulated conductor, which immediately receives the electricity from the excited electric.

The electric was formerly used of various substances and various shapes. At present glass globes, or glass cylinders, or circular glass plates, are almost all the variety that is used, and which indeed are the most advantageous. The most usual size for the globes is from 9 to 12 inches in diameter; and they are mostly made with one neck. The cylinders are made with two necks, and they are of all sizes, even as far as 24 inches in diameter. The glass plates are also of various sizes. The glass generally used in this country for such purposes is the best flint glass.

With respect to the engine, which is to give motion to the electric, multiplying wheels have been generally used, which might move the electric with considerable velocity, whilst they are commodiously turned by a winch. A wheel and an endless screw has also been used, but this is apt to make a rattling noise, and soon wears away. But either a cylinder or a circular plate may be moved quite quick enough by means of a simple winch, to which the hand is immediately applied.

The rubber is the next article which must be described. After a variety of trials it appears that the best

rubbers for a globe or a cylinder are made of leather stuffed with hair, and a pretty long piece of fine silk is fastened to one side of the rubber,* and after having passed over the rubber, viz. between the cushion and the globe or cylinder, spreads over more than one third part of the circumference of the latter. For a plate the rubbers mostly consist of a piece of leather with a piece of silk at its extremity, or of cushions, &c.

The proper construction of the rubber requires, that the side of it which the surface of the glass enters in whirling, may be as perfect a conductor as possible, in order to supply the glass with electric fluid, and that its other side be as much a non-conductor as possible, in order that none of the fluid which is accumulated upon the glass may return to the rubber.

The rubber should be supported by a spring, by

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* A simple rubber, such as is here described, will produce a very slight excitation of the cylinder; but its power is vastly increased by laying upon it a little amalgam of tin, and especially an amalgam of zinc. The best way of using this amalgam is as follows: First make the rubber with the silk flap very clean and dry, and put it in its place, as at RI, fig. 70; then spread a little of the amalgam upon a piece of leather, and apply it to the under part of the cylinder, while this is revolving in the direction of the letters, a, B, c; for by this means particles of the amalgam will be carried by the glass itself to the lower part of the rubber, and will increase the excitation prodigiously. The leather with the amalgam needs not be kept against the cylinder longer than it may be required to produce the desired effect; for when the excitation decreases, the leather may be applied again.

The amalgam of tin is made with two parts of quicksilver, and one of tin-foil, with a small quantity of powdered chalk, mixed together until it becomes a mass like paste. To make the amalgam of zinc, let four or five parts of quicksilver be heated higher than the degree of boiling water, and let one part of zinc be melted in a crucible or in an iron ladle. Pour the heated quicksilver into a wooden box, and immediately after pour the melted zinc into it. Then shut up the box, and shake it for about half a minute. After this you must wait until the amalgam is quite cold, or nearly so, and then you may mix it, by trituration, with a small quantity of grease, such as tallow or mutton-suet, a very small portion of finely powdered whitening, and about a fourth part of the above amalgam of tin.

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which means it may easily suit the inequality of the glass, and the spring should be fixed fast upon a glass pillar or other insulating stand; it being useful to have the rubber insulated in several experiments; but when its insulation is not required, a chain or wire is easily suspended to it, and thus it may be made to communicate with the earth, or with any other body at pleasure.

The *prime conductor* is nothing more than an insulated conductor which is situated with one of its extremities contiguous, but not quite in contact, with the electric, and nearly opposite to the rubber. This conductor may be made of hollow brass, or of tin plates, or of pasteboard covered with tin-foil, or of wood covered with tin-foil, &c. Its shape is generally cylindrical with semiglobular terminations. But be the shape what it may, care should be had to make it as free as possible from points, sharp corners, sharp edges, &c. for these throw off and dissipate the electric fluid; but on the end which is contiguous to the electric, it must have a short pointed wire, or two, or more, which are called the *collector*, and will readily receive the electricity.

The size of the conductor should be proportionate to the size and power of the electric. The larger the prime conductor is, the denser and longer sparks may be drawn from it, provided the electric be sufficiently powerful. But beyond a certain size, the dissipation from the surface may be greater than what the electric can supply, and in that case the large conductor is disadvantageous.

Upon those principles electrical machines of a vast variety of shapes and sizes have been constructed in this as well as in other countries. But amongst all that variety, we shall describe two only, which, upon the whole, are the most commodious, and are more generally useful.

Fig. 70. represents an electrical machine of the simplest sort. GEF is a strong board, which supports all the parts of this machine, and which may be fastened to a strong table by means of one or more iron or brass clamps, as at Q. The glass cylinder AB, quite clean and dry in its inside, is about 10 inches in diameter, and is

furnished with two caps, either of wood or brass, into which its two short necks are firmly cemented.* Each of those caps has a pin, or projection, or pivot, which turns in a hole through a wooden piece, that is cemented on the top of a glass pillar, as at A and B on the glass pillars BE, AG, which are firmly fixed to the bottom board GEF. One of the above-mentioned projections passes quite through the wooden piece, as at A, and has a square termination, to which the winder AD is applied and secured on by means of a screw nut. Then by applying the hand at D, the operator may turn the cylinder, &c. Sometimes the part AC of the winder is made of glass, in order the more effectually to prevent the escape of the electric fluid from the cylinder. IR is the rubber, and IRK is the silken flap.† This cushion or rubber is fastened to a spring, which proceeds from a socket cemented on the top of the glass pillar S. The lower part of this pillar is fixed into a small board which slides upon the bottom board of the machine, and by means of a screw nut and a slit at H, may be fixed more or less forward, in order that the rubber may press more or less upon the cylinder. NF is a glass pillar which is fixed in the bottom board, and supports the prime conductor ML, of hollow brass or tin plates, which has the collector or pointed wires at L, and a knobbed wire at M. From this brass knob O, a longer spark may be drawn than from any other part of the conductor. But this knobbed wire is only screwed into the conductor, and may be easily removed from it.‡

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* The best cement for this purpose is made by melting and incorporating together 5 parts of rosin, 4 of bees-wax, and 2 parts of powdered red ochre.

† The silk generally used for this purpose is what is commonly called *black mode*.

‡ As glass is apt to attract moisture from the air, in which case it conducts the electricity over its surface; therefore it is proper to cover with sealing-wax, or to varnish over, the glass pillars of this machine, as also all those glass articles which serve for insulating; for when varnished, and especially when covered over with sealing-wax in the dry way, they attract the moisture, either not at all, or in an incomparably smaller degree, and of course they insulate vastly better.

In order to cover glass with sealing-wax in the dry way, warm the glass gradually near the fire, and when sufficiently warm, rub a stick of sealing-wax gently over its surface; for by this means the sealing-wax is melted, and adheres to the glass. In the humid way, the sealing-wax must be dissolved in very good spirit of wine, for which purpose you need only break the sealing-wax into small bits, and leave it in the spirit of wine for a day or two, shaking it now and then.—This solution must be laid upon the dry and clean glass, by means of a hair pencil, and when the first coat of it is

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The simplest construction of the plate machine is represented by fig 71. which requires very little explanation. ABCDM is a wooden frame, to which the four rubbers are affixed, which, by means of the screws *g, g, g, g*, may be made to bear with proper pressure upon the circular glass plate HK.* This plate has a hole through its middle, to which an axis ML is firmly fixed, in the manner indicated by the magnified side view, fig. 72, and is turned by means of the winch LG. The prime conductor has a branched termination with points at the extremities, which collect the electric fluid from the fore part of the glass plate.

Some plate machines have been made with two glass plates and eight rubbers, and when properly constructed, especially as they are made by Mr. Cuthbertson, their power is very great. Indeed the most powerful electrical machine now extant is, as far as I know, one of this construction made by the above-mentioned philosophical instrument maker, for the museum of Teyler, at Harlem; a particular description of which was given to the public by Dr. Van Marum.†

This machine consists of two circular plates, each 65 inches in diameter, fixed on a common axis, parallel to each other, and 7½ inches asunder. Each plate is excited by 4 rubbers; the prime conductor is divided into two branches, which enter between the plates, and, by means of points, collect the electric fluid from their inner surfaces only.

The plate machines may in general be made more compact and more powerful than other electrical machines, but they are liable to a considerable degree of friction, and of course they are not easily worked.

In the plate machines the rubbers are not easily insulated, yet this has been accomplished by various, rather complicated means.‡

Besides the electrical machine, the operator ought to have some glass tubes, and one or two pretty large sticks

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quite dry, then a second, a third, and even a fourth coat should be laid on.

The best varnish for this purpose is the amber varnish, which indeed answers as well as the sealing-wax in the dry way, but it must be made with great care and caution.—See the particular description of the process in my Treatise on Electricity, 4th edition, vol. III. p. 296.

* The rubbers generally consist of oblong cushions that are frequently affixed to springs; but sometimes they are only pieces of leather spread upon wood, to which silken flaps are affixed, &c.

† See a compendious description of its effects in my Treatise on Electricity, 4th edition, vol. II. p. 273.

‡ See the descriptions of those machines in letters from Dr. Van Marum to the Chevalier M. Landriani, and to Dr. Ingenhousz; both printed at Harlem in 1789 and 1791.

of sealing wax, which are of great use in a variety of experiments.—The best rubber for the excitation of a glass tube is the rough side of black oiled silk, especially when a little amalgam has been rubbed over it; but soft new flannel is the best rubber for sealing-wax, sulphur, rough glass, or baked wood; every one of which substances, when rubbed with flannel, will acquire the negative electricity.

151. The instruments necessary for the accumulation of electricity, are coated electrics, amongst which glass has justly obtained the principal place. The form is immaterial; but the thickness and the quality of the glass should be noticed. Thin glass can receive a greater charge; but it is at the same time more liable to be broken by the discharge. A single jar may be pretty thin, but such jars as are to form a large battery must be a little thicker. When their openings are narrow, those jars may be coated on the inside with brass filings, which are stuck by means of gum-water, or paste, or melted wax; but when their openings are sufficiently large, they may be coated on their inside as well as on the outside with tin-foil, or sheet lead, or gilt paper, either of which may be stuck with paste, or varnish, or gum-water, &c.

Fig. 73. represents an electric jar, coated with tin-foil on the inside and outside, within about three inches of the top of its cylindrical part; and having a wire with a round brass knob, or ball A, at its extremity. This wire passes through the cork or wooden stopple D, and its lower extremity touches the inside coating.

Fig. 74. represents a battery consisting of 16 jars, coated with tin-foil, and disposed in a proper box. The wires, which proceed from the inside of every four of those jars, are screwed, or soldered or fastened to a common horizontal wire E, which is knobbed at each extremity, and by means of the wires F, F, F, the inside coatings of 8, or 12, or all the 16 jars may be connected together.

The inside of the box which contains those jars, is likewise lined with tin-foil or tin-plates, for the purpose of connecting more effectually the outside coatings of all the jars. On one side of this box there is a hole, through which a strong wire or hook passes, which communicates with the lining of the box, and of course with the outside coatings of the jars. To this hook a wire is occasionally fastened, which connects it with one branch of the discharging rod BBCA.

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The discharging rod consists of the glass handle A, cemented into the brass socket C, and the curved wires B, B, which may be opened and shut, like a pair of compasses, by a joint at C. The extremities of those wires are pointed, and the points enter the brass knobs D, D, to which they are screwed, and from which they may be unscrewed at pleasure. With this construction we may use either the points or the balls, and the instrument may be used for discharging jars of various sizes.

152. Fig. 75. represents Henley's Universal Discharger, which is a very useful instrument in a great variety of experiments. A is a flat board or pedestal about 15 inches long, 4 broad, and 1 thick. B, B, are two glass pillars, fixed fast into the board A, and furnished at top with brass caps, each of which has a vertical joint, and supports a spring-tube, through which the wire DC slides. Each of those caps consists of three pieces so connected as that the wire DC, besides its sliding through the spring-socket, has two other motions, viz. a horizontal and a vertical one. Each of the wires DC, DC, is turned into a ring at one end, and at the other end has a brass ball D, which, by means of a short spring socket, is slipt upon its pointed extremity, and may be removed from it at pleasure. E is a strong piece of wood, or tablet, about 5 inches in diameter, having on its surface a slip of ivory inlaid, and is furnished with a strong cylindrical foot that fits the cavity of the socket F, which is fastened into the bottom board A, and has a screw G, which serves to detain the foot of the circular tablet E at any required height. H is a small press which belongs to this instrument. It consists of two oblong pieces of board, which may be pressed against each other, or against any thing that may be interposed, by means of the screws and nuts *a*, *a*. The lower of those boards has a cylindrical foot equal to that of the board E. When this press is to be used, it is fixed into the socket F, in the place of the circular board E, which must, in that case, be removed.

153. The instruments which either manifest the presence, or manifest the presence and the quality, or measure the quantity of electricity, are called *electrometers* or *electroscopes;* and they have been made of a great variety of shapes, from which, as also from their uses, they have derived peculiar appellations.

A simple thread, or a feather, or other light body, simply suspended by a fine thread, may be used for exploring whether a body be electrified or not; for if the body be electrified, and be brought near it, the thread, or other light body, will be attracted by it.

The simplest electrometer for ascertaining the quality as well as the presence of electricity, has been already

described; it is represented by fig. 68. and 69., and is called, from its inventor, *Canton's electrometer.* (127.).

Fig. 76. represents *Henley's Quadrant Electrometer*, fixed upon a small circular stand, from which it may be occasionally separated, and may be fixed upon the prime conductor, or elsewhere. This electrometer indicates the quantity, or rather the condensation, of electricity. It consists of a perpendicular stem of box wood, with a globular termination at top, and having a brass ferrule at its lower extremity, by which it may be fixed upon the prime conductor, or upon the electrical battery, &c. To the upper part of the stem a graduated ivory semicircle is fixed, about the middle of which is a brass arm, which contains a pin or axis of the index. The index consists of a very slender stick of box wood, which reaches from the centre of the graduated semicircle to the brass ferrule, and has a small cork ball fastened to its lower extremity. When this electrometer is not electrified, the index hangs parallel to the pillar, and its cork ball touches the brass ferrule, as in fig. 76.; but when electrified, the index is repelled by, or recedes from, the stem more or less, according to the intensity of the electricity; and the graduation on the ivory semicircle shows the force or the elevation of the index, as at P in fig. 71.*

The principle of Lane's Discharging Electrometer, as is now commonly used, especially by the practitioners of medical electricity, is shown in fig. 77. It consists of a glass arm D, which proceeds from a socket on the wire of the electrical jar F, and to the top of which a brass spring-socket E is cemented; through this socket a brass wire, with the ball B at one end and the ring C at the other, may be slid backwards and forwards. The wire BC is generally marked with divisions of inches and tenths. When the jar F is set in contact with the prime conductor, as represented in the figure, and the ball B is set at the distance, for instance, of one

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* A vast number of alterations have been made to this electrometer, viz. the index has been enclosed between two ivory semicircles; the whole has been made of brass, with multiplying wheels, and a counterpoise has been put to the index, in order to render a small force of electricity more perceptible, &c. but, after all, the simple original construction, as described above, seems preferable.

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tenth of an inch from the ball A, let a wire CK be fixed between the ring C of the electrometer, and the outside coating of the jar; then, when the electrical machine is in action, the jar F cannot be charged beyond a certain point; for when the charge is strong enough to leap from the ball A to the ball B, the discharge will take place, and the shock will pass through the wire CK, or through a human body, or through any other conducting body that is placed, instead of the wire CK, to form the communication. Thus by situating the ball B further from the ball A, stronger shocks may be given, as far as the same jar is capable of.*

In performing several atmospherico-electrical experiments about the year 1776, I found that the use of Canton's cork-ball electrometer was much obstructed by the wind, in consequence of which I attempted to enclose it in a bottle, and after a variety of trials and alterations the instrument was in the year 1777, brought to the state which is represented in fig. 78., of which the part ELF represents the brass cap and neck of the instrument.

CDMN is an open glass vessel narrower at top than at bottom, and cemented into the wooden piece AB, by which part the instrument is held when it is to be presented to the atmosphere, or it may be rested upon a table for other experiments. (This wooden piece also serves to screw the instrument into its wooden case.) The upper part of CDMN is tapering like the neck of a phial, and a short glass tube is cemented into it, so as to project a little above and a little within the neck of the former. Then the upper part of the instrument, from CD to L, is covered with sealing-wax, by means of heat, which gives it the appearance of one continuate body. The inner part G of the small glass tube is also covered with sealing-wax. Into this tube a brass wire is cemented, the lower part H of which is flattened, and is perforated with two holes; the upper part L is formed into a screw, upon which the brass cap EF is screwed. The office of this cap is to defend the upper part of the instrument from the rain. The conical, or oval, or globular, corks P of this electrometer, are as small as can be made, and are suspended by exceedingly fine silver wires, the upper parts of which are formed in rings, which pass through the holes at H, and are thereby so loosely suspended, that they are caused to diverge when the brass cap E is exposed to a very slightly electrified atmosphere. IM and KN are two narrow slips of tin-foil stuck to the inside of the glass, and communicating with the wooden bottom AB;—they serve to carry off that electricity, which, when the corks touch the glass, is communicated to it, and if accumulated would disturb the free motion of the corks.†

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* This electrometer has likewise undergone a great many alterations. An improvement of it, and a combination of this and other electrometers was made by Mr. Cuthbertson.—See a description of it in Nicholson's Journal of Nat. Phil. &c. vol. II. p. 528.

† A useful alteration of this electrometer was made by Mr. Bennet. It consists of two slips of gold-leaf, or silver-leaf, suspended from the cover of, and hanging within, a cylindrical glass vessel, instead of the corks suspended by wires or threads. The slips of gold are about 2½ inches long, and sometimes they are narrower at their lower extremities. This electrometer is the most sensible instrument of the kind, and very useful in nice experiments; the gold slips being caused to diverge in a ready and unequivocal manner by very small quantities of electricity; but the instrument, thus furnished, is by no means portable. (See the description of it in the Phil. Trans. vol. 77.) If very fine threads stiffened with glue, be used without any balls, they will be found nearly as sensible as the slips of gold leaf.

Such are the most essential parts of the electrical apparatus. But there is a great variety of particular instruments, which are to be used for the performance of peculiar experiments; but the description of these, as well as the necessary instructions for the management of the same, and for the general performance of experiments, will be found in the sequel.

CHAPTER VI.

Electrical Experiments.

154. THE principal object of this chapter is, to describe such experiments as are more essentially necessary for proving the laws which have been stated in the preceding chapters of this section.—A few very trifling articles, such as a glass tube, a stick of sealing-wax, or a piece of amber, and two or three electrometers, will be sufficient to prove the leading propositions of electricity.

But the electrical machine being the principal article of a pretty large electrical apparatus, we shall begin by explaining the proper management of the same.

When the weather is clear and dry, especially in serene and frosty weather, the electrical machine always works well. In very

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hot or damp weather, the machine does not work well; therefore more attention is required in the latter circumstance than in the former; yet, with proper care, the electrical machine may at all times be made to work with sufficient power, by attending to the following instructions.

Before the machine be used, the cylinder should be wiped very clean and dry, and in cold weather it should be gently warmed by keeping it a little while at a moderate distance from a common fire. This done, if the winch be turned, when all other things are removed, and the knuckle be held at a little distance from the surface of the cylinder, about the middle of it, and opposite to the rubber, the electric fluid will come from the cylinder to the knuckle, and the sparks, accompanied with a crackling noise, will soon be perceived. But should this not take place after about 20 or 30 turns of the cylinder, take off the rubber from its glass pillar, clean it well, and place it near the fire, in order to dry at least the silk flap;—wipe the cylinder well with a warm flannel or warm silk handkerchief, and replace the rubber, so that it may bear upon the cylinder with sufficient force; then hold the piece of leather with the amalgam against the cylinder at its under part while you turn the winch, and the machine will soon acquire its power. When this has taken place, remove the leather with the amalgam; place the prime conductor before the cylinder, as in fig. 70., wipe its stand NF quite clean and dry, and make a good communication, by means of a wire or otherwise, between the rubber and the ground; then turn the winch, and the electric fluid, in the form of sparks, may be drawn from the prime conductor, by presenting a blunt uninsulated conductor to its surface. The longest spark may be drawn from the knob O. If the point of a pin be presented to the prime conductor whilst the cylinder is revolving, a luminous globule of light will be seen upon the point, which is not attended with any noise. If the communication between the earth and the rubber be removed, and it be made between the earth and the prime conductor, then, on presenting a pointed pin to the rubber, a brush or pencil of light will be seen issuing from the point, and tending towards the rubber.

If, when the communication is made between the earth and the prime conductor, a simple electrometer, viz. two cork balls fastened at the ends of two threads, be suspended to the knobbed wire MO; these will hang down touching each other, as long as the machine is not in action; but the least turning of the cylinder will make them diverge, or fly from each other. If, in this state of repulsion, you touch the prime conductor with an electric, as with a piece of glass, or sealing-wax, or amber, or sulphur, &c. the cork balls will continue to diverge; but if you touch it with any uninsulated conductor, such as your finger, or a wire, or a piece of charcoal, &c. the threads with the balls will immediately collapse. And this is a ready way of trying whether a given body be a conductor or not.

Now, according to the theory, the cylinder is enabled, by the friction, to draw the electric fluid, which naturally existed in the rubber, and throws it upon the prime conductor, from which, on account of the insulation, it cannot fly away, except what is communicated to the air, or what flies off in the form of sparks to any conductor that may be presented to the prime conductor.

If the rubber be insulated, the electrical machine will lose almost all its power, because the rubber, after having supplied the cylinder with its own fluid, cannot receive any more, except a very little quantity of it from the surrounding air, which is seldom, if ever, a perfect electric.—The influx of electric fluid to the rubber, and the efflux from the prime conductor, is shown by the luminous pencil or star, which is seen on the pin or pointed conductor that is presented to them.

If, when the cork balls are diverging at the end of the prime conductor, as mentioned above, you present to them an excited glass tube, or any other body positively electrified, the balls will fly from it; but they will run towards an excited piece of sealing-wax, or towards any other body negatively electrified; and this is a ready way of trying whether an electrified body be positive or negative.

Sometimes another prime conductor is placed in contact with the rubber RI; then the communication being made between the prime conductor ML and the earth, the above-mentioned experiments may be made with the other prime conductor, but with this difference, that in the latter case they are affected by negative electricity, and show signs of that electricity: hence, this conductor is called the *negative*, and ML is called the *positive*, conductor.

The Flying Feather.

155. Take an excited glass tube in one of your hands, and let a small light feather be left in the air, at the distance of about 8 or 10 inches from the tube. This feather will be immediately attracted by the tube, and will adhere very closely to its surface during a few seconds, and sometimes longer; then, having acquired the same sort of electricity, it will be repelled, and by keeping the tube under it, the feather will continue to float in the air at a considerable distance from the tube, without coming near it again, except it first touches some conducting substance, upon which it can deposit the acquired electricity. By managing the tube dexterously you may drive the feather to any part of the room at pleasure.

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A remarkable circumstance attends this experiment, which is, that while you keep the feather from the tube, and move the latter about the former, the feather always presents the same part towards the tube; the reason of which is, that when the equilibrium of the electric fluid amongst the parts of the feather is once disturbed, it is not easily restored, on account of the feather being a very bad conductor.

The Electric Well.

156. Place upon an insulating stand, (viz. a stool with glass legs) a metal pint or quart mug, or some other conducting body nearly of the same shape; then fasten a short cork ball electrometer, like that of fig. 68., at the end of a silk thread, proceeding from the ceiling of the room, or from any other proper support, so that the electrometer may be suspended entirely within the mug. This done, electrify the mug, by giving it a spark with an excited electric, or otherwise, and you will find that the electrometer, whilst it remains in that insulated situation, and even if it be caused to touch the inside surface of the mug, will not be attracted by it, nor will it acquire any electricity; but if a conductor, partly standing out of the mug, be made to communicate with the electrometer, then the latter will be immediately attracted by the mug.

In this experiment the electrometer is acted upon from all sides by the electricity of the mug, and having no body upon which it can deposit its electric fluid, or acquire any from, cannot acquire the contrary electricity, and of course cannot be attracted; but when another conductor is presented to it, then the attraction takes place, because the electrometer in that case acquires some electric fluid from, or can deposit its fluid upon, that conductor.

To show the action of Electric Atmospheres.

157. Let a body be electrified, for instance, positively, and if at some distance from it you hold an electrometer of cork balls, this electrometer will be found to diverge, but with negative electricity; which may be easily proved; for if you present to it an excited piece of glass, the cork balls will run towards it; but they will fly away

from excited sealing-wax, supposing this to be excited always negatively, and the glass always positively.

Insulate in a horizontal position a metallic rod with blunt terminations, as AB, fig. 79., about two feet long, and having a cork-ball electrometer at its extremity A; then bring within 8 or 10 inches of its other end B an excited glass tube; and the balls C will immediately diverge with the same, viz. with positive electricity. If the tube be removed, the balls will immediately come together, and no electricity will remain in them or in the rod. But if, while the tube is near one end B of the rod, and the cork balls diverge with positive electricity, the other end A be touched with a finger, or with any uninsulated conductor, the cork balls will immediately collapse, remaining as if the rod were perfectly unelectrified; but if, in this state of things, the excited tube be removed, the balls will immediately diverge with negative electricity, showing that the rod AB is undercharged.

This experiment is easily explained; for when the rod is in a natural state with respect to electricity, then the electric fluid naturally belonging to it, is equably diffused throughout the rod; but when the excited tube is brought within a certain distance of one of its ends, as B, then the fluid belonging to that end will be driven towards the extremity A; which extremity therefore becomes overcharged, and the other extremity B undercharged, yet the rod has no more electric fluid now than it had before; and when the tube is removed beyond the sphere of its action, the superfluous fluid of the extremity A returns to its former place B, and the equilibrium is restored. But if, whilst the extremity A is overcharged, the same extremity be touched, then its superfluous fluid will be conducted away by the touching body, leaving the extremity A in a natural state; but at the same time the extremity B is undercharged; therefore, when afterwards the tube is removed, part of the fluid naturally belonging to the extremity A, goes towards B, and of course the whole rod will remain undercharged, or electrified negatively.

This experiment, which may be endlessly diversified, and so simplified as to be performed with a simple cork-ball electrometer, shows how an electrometer or other body may be electrified negatively by means of a body electrified positively, or *vice versa*.

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To show the alternate attraction and repulsion of the same light bodies.

158. Place upon a flat metallic plate any small bodies, such as pieces, or small figures, of paper, or bits of gold-leaf, bran, &c. and whilst the machine is in action, hold the said plate directly under the prime conductor at about 3 or 4 inches distance from its surface; and the light bodies will soon move between the plate and the conductor, leaping alternately from the one to the other.

In this experiment the small bodies and the plate, by being within the sphere of action of the electrified prime conductor, become actually possessed of the contrary electricity, leaving their electric fluid upon the hand of the operator, or other body that communicates with the plate: hence the light bodies (on account of the attraction between bodies differently electrified) are attracted by the prime conductor. Now as soon as these bodies touch the prime conductor, they become instantly possessed of the same electricity with it; therefore they are repelled (on account of the repulsion between bodies possessed of the same sort of electricity), but they are attracted by the plate, which is in a contrary state, &c.

If the conductor be supposed to be electrified negatively, the explanation requires a very trifling and very obvious alteration of expressions.

That the small light bodies cannot be attracted by the conductor, unless they become first possessed of the contrary electricity, may be proved in the following manner:—Place the said light bodies upon a clean and dry pane of glass, instead of the metallic plate, and holding the glass by one corner, place it under the electrified prime conductor. It will be found, that the small bodies are not attracted, because in this case they have no opportunity of parting with their natural electric fluid, and consequently cannot acquire the contrary electricity. But if a finger or any other conductor be presented to the under side of the pane of glass, then the light bodies will be instantly attracted, repelled, &c. for these bodies can now deposit their electric fluid upon the upper surface of the glass plate, whilst the under surface of the glass deposits its fluid upon the finger, or other conductor. If this experiment be continued, the pane of glass will soon be charged.*

* The preceding experiments show the following facts, or laws, which we shall assume as axioms, to prove that the repulsion of bodies possessed of the same sort of electricity, be it positive or negative, seems to be clearly explicable on the theory of a single electric fluid.

1. A body possessed of either sort of electricity will induce, or tend to induce, the contrary electricity on any other body that comes within its sphere of action, viz. within a certain distance of its surface.

2. A body cannot appear electrified on any part of its surface (meaning that the electrical power cannot manifest itself, or, according to the theory, the electric fluid cannot be equably diffused through it,) unless that surface is opposite to some other body which is actually possessed of the contrary electricity. And those two contrarily electrified bodies attract or tend to attract each other.

3. According to the Franklinean hypothesis, the electric fluid is elastic, that is, repulsive of its own particles, but attractive of the particles of other matter.

Now let A and B, fig. 80., be two spheres of conducting matter, suspended in the open air, contiguous to each other, and capable of being easily moved. Let some electricity be communicated to them, and it is evident that this electricity cannot be diffused equably over their surfaces, but it must be thicker or more condensed on the parts that are remote from the point of contact, because there the air is at liberty to acquire the contrary electricity; whereas near the point of contact, the electricity cannot be manifested, because in that place there is no air or other body which can acquire the contrary electricity. Therefore the atmospheres of contrary electricities cannot be concentric with the spheres A and B, but must be situated somewhat like the dotted representation of fig. 80.; then the spherical bodies being attracted towards the centres of those spheres, appear to repel each other, as shown in fig. 81.; so that when the bodies are electrified positively, negative atmospheres will be formed round them, and the additional electric fluid of the bodies will attract, and be attracted by, those negative atmospheres. When the bodies are electrified negatively, positive atmospheres will be formed round them, which attract the undercharged bodies.

This explanation may be easily applied to bodies of any other shape; proper allowance being made for their more or less perfect conducting or nonconducting nature.

Experiments with the Leyden Phial.

159. Place a coated jar, such as that of fig. 73., upon the table where the electrical machine stands, and with its knob A, in contact with the prime conductor, also place Henley's quadrant electrometer upon the prime

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conductor; then work the machine, and the index of the electrometer will rise gradually as far as a certain height, which depends upon the force of the machine, size of the jar, &c. beyond which it will not rise. You may then conclude that the jar has received its full charge.* Take a discharging rod, and, holding it by its glass handle, apply one of its knobs to the outside coating of the jar; then bring its other branch towards the knob A of the jar, and you will hear a report, and see vivid sparks between the discharging rod and the conducting substances that communicate with the sides of the glass. This operation discharges the jar. If, instead of using the discharging rod, you touch the outside of the jar with one hand, and its knob with the other hand; then, besides the report, &c. you will feel a peculiar shock, which, according to the height of the charge, size of the jar, &c. will affect either your wrists, or elbows, or breast, &c. If a number of persons join hands, and the first of them touches the outside of the jar, and the last touches the knob, they will all feel the shock, and precisely at the same perceivable instant. But those who are nearer to the coatings of the jar, or who are at the extremities of the circuit of communication, will feel the shock stronger than the rest; for the electricity of either side becomes less condensed, and of course less active in proportion as it expands itself through a greater quantity of conducting matter.

The force of the discharge may be manifested by a great variety of experiments.—Take a card or quire of paper, or two cards kept a little asunder by the interposition of little bits of wax here and there; place either of those articles flat against the outside coating of a charged jar, and put one of the knobs of the discharging rod

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* Some sort of glass is more apt to discharge itself over its surface than others. A battery cannot in general be charged so high as a single jar. The dampness or dryness of the air does also influence the charge. Yet Mr. Cuthbertson found, that by breathing into a jar through a glass tube, previous to the charge, the jar will be enabled to hold a much greater charge. He judges of the force of a battery or jar by the length of wire which its discharge is able to fuse.

over it, so that the card or quire of paper, or the two cards, may be interposed between that knob and the coating of the jar; then, by bringing the other knob of the discharging rod near the wire of the jar, make the discharge; and the electric matter, rushing through the circuit from the positive to the negative side of the jar, will pierce a hole, and frequently more than one hole, quite through the card or cards, or quire of paper, &c.; and each hole will be found to have a bur raised on each side, unless the card be pressed too hard against the side of the jar.* If the nostrils be immediately presented to such perforation, a smell, somewhat like that of phosphorus, will be perceived. If, instead of paper, a very thin plate of glass, or of rosin, or of sealing-wax, be interposed between the discharging rod and the outside coating of the jar, on making the discharge, this will be broken in several pieces.

If a piece of white sugar be interposed, and the shock be sufficiently strong, the sugar will be broken, and in the dark it will appear beautifully illuminated, remaining so for nearly a minute after.

160. Put the extremities of two wires upon the surface of a card, or, which is the same, place the card flat upon the tablet E of the universal discharger, fig. 75., and having removed the knobs D, D, incline the wires, so that their extremities may rest upon the card, and at about an inch distance from each other; then, by connecting one of the rings, or wires C, with the outside of a charged jar, and the other wire C with the knob of the jar, the shock will be caused to pass over the card; and after the same manner it may be caused to pass over the surface of any other body.

If the card be very dry, the discharge will leave upon the card between the extremities of the two wires a lucid track, which will remain upon it during some seconds. If the shock be passed over a piece of writing paper, this will be torn into very small bits. If the shock be sent over a piece of glass plate, the surface of the glass will thereby be marked with an indelible track.†

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* This shows, that the bur and the perforation are made by the expansion of the substance of the card or paper.

† If the card, over which the shock is sent, be painted with any particular colour, a permanent black mark is generally left upon it, especially if it be painted with vermilion.

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In this experiment the glass plate is seldom broken; but Mr. Henley found that it may be easily broken if weights have been previously laid upon it. He used to place a thick piece of ivory upon that part of the glass which stood between the extremities of the wires, and upon that ivory he placed any weight from a quarter of an ounce to six pounds. On making the discharge, the glass would generally be broken into innumerable pieces, some of it being absolutely reduced into an impalpable powder. If the glass be too thick to be broken by the force of the explosion, it will be found marked with the most lively prismatic colours, which are occasioned by very thin laminæ of the glass, partly separated by the shock. The weight is always shook by the explosion, and sometimes is quite thrown off from the ivory.

161. In order to fire gunpowder by means of the Leyden phial, make a small cartridge of paper, and fill it with gunpowder, or else fill the tube of a quill with it, and insert the pointed extremities of two wires in it, so that their extremities within the powder may be about one-fifth part of an inch from each other. This done, send the charge of a Leyden phial through those wires, and the gunpowder will be fired. If the powder be mixed with steel filings, the experiment will succeed even with a small shock.

If the gunpowder be placed loosely upon any stand, and the interruption of the wire circuit be made in it; on making the discharge of the jar, the spark which takes place at that interruption, will scatter the gunpowder without firing it. But the loose gunpowder may be fired, if the shock be transmitted through less perfect conductors; in which case the discharge being less sudden, or rather proceeding in a stream, the powder will be fired. The best method of performing this experiment is shown in fig. 82.

F is the gunpowder, placed upon the same table upon which the jar AB is situated; CD is a glass tube about one foot long and a quarter of an inch in diameter, full of water, and having two corks at its extremities. Into these corks two wires are thrust, the inner extremities of which just touch the water, viz. the short wire at D, and the long wire CA, which makes the communication between the water of the tube and the knob of the jar. On making the discharge, which must pass through the small quantity of water in CD, and through the table FB, both imperfect conductors, the electric fluid comes out at D, in the form of a dense stream, which generally fires the gunpowder at F.

162. If a spoon, containing spirit of wine, be connected with the outside of a Leyden phial, and the knob of a wire, communicating with the inside of the phial,

be brought just over the surface of the spirit, at a small distance from it, the discharge of the phial will set fire to the spirit of wine, provided this has been previously warmed. But the same thing may be done by passing a simple spark from the prime conductor of the machine through the warmed spirit of wine.

163. A very fine slender wire may be fused by the discharge of a single jar. For this purpose you need only make that wire part of the circuit; for instance, place it between the extremities of the wires of the universal discharger. The fine turnings or shavings of steel are very easily fused, even by a small shock. But a wire of the 50th part of an inch or upwards, requires a considerable battery to melt it.*

164. Take two slips of common window glass, about three inches long and half an inch broad; put a small slip of gold, or silver, or brass-leaf between them, leaving a little of the metallic leaf out of the glasses at the two ends, and place those glass slips between the boards of the press H of the universal discharger, fig. 75., which press must be put in the place of the tablet E; then by connecting the wires D, D, with the projecting extremities of the metallic leaf, &c. send the charge of a pretty large jar through it; the consequence will be that the glasses are generally shattered by it; but whether they are broken or not, they will be found indelibly marked by the metal, which is forced so far into the pores of the glass, as not to be affected even by the menstrua which otherwise are wont to dissolve it.

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* It appears that the highest charge of a battery, belonging to Dr. Van Marum, and containing 135 square feet of coated surface, could just fuse 180 inches of iron wire, $\frac{1}{150}$ of an inch in diameter, or 6 inches of iron wire, $\frac{1}{40}$ of an inch in diameter. Another battery belonging to the same person, and containing 225 square feet of coated surface, could melt, with its highest charge, 300 inches of the first-mentioned wire, or 10 inches of the last. Also the highest charge of a third battery, which contained 550 square feet of coated surface, could fuse 25 inches of the latter wire. Nicholson's Journal of Natural Philosophy, &c. vol. II. page 527.

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165. Take a wire of the size of a common knitting-needle, or larger, and by means of an easily flexible wire or chain, let one end of it communicate with the outside coating of a jar, that contains at least ten square inches of coated surface. Round the other end of the first-mentioned wire, some cotton must be loosely twisted, so as to form a head round it, and thus conceal the end of the wire. Roll this head of cotton in powder of lycopodium, or in powder of rosin: this done, charge the jar, and bring the cotton head rather quickly towards its knob; by which means the discharge will be caused to pass through the said cotton, which will thereby be instantly set on fire.

166. If a jar be discharged with a discharging rod that has not an electric handle, the hand which holds the rod, on making the discharge, feels a partial shock. In other words, a person, or any conducting substance that is connected with one side of a Leyden phial, but that forms no part of the circuit, will feel some effect of the discharge. Thus, if you connect a piece of a chain with the outside of a jar, or place it very near the jar; then discharge the jar through another circuit, as for instance, by means of a common discharging rod; on making the discharge in the dark, sparks will be seen between the links of the chain, also between the chain and the jar; which shows that the electric fluid of the chain is affected by the proximity of the jar. If this chain be insulated, it will be found, after the discharge of the jar, not to be electrified: hence Dr. Priestley (who first described this effect out of the circuit, and to which he gave the name of *lateral explosion*) thinks that this lateral spark flies from the coating of the jar to the chain, and instantly returns to the former.

167. Thus far I have described such experiments as show the effects or the power of charged electrics, and which may be mostly performed with a single jar.

That power may be shown in a much more surprising manner by the use of a large battery; but the management of such a battery being similar to that of a single jar, it is needless to give any particular directions respecting the use of the same. We may only observe, by way of precaution, that more care and attention is required in the management of a large battery, lest the shock, which might be very hurtful, should unexpectedly pass through the operator, or any of the by-standers.

After having discharged a large battery, the operator should once more apply the discharging rod to the outside and inside coatings of the battery; for a residuum of the charge generally remains in it after the first discharge, which might afterwards give an unexpected shock. The same precaution may be extended to a single large jar.

168. I shall now relate such experiments as may illustrate the theory of the Leyden phial, and the hypothesis of a single electric fluid.

Place a coated jar on an insulating stool, and with its knob, not in contact, but within an inch of the prime conductor; then work the machine, and after a certain time you will find, upon trial, that the jar is not charged, because its outside, being insulated, could not part with its electric fluid, and of course its inside could not receive any additional quantity of it. But if you hold the knob of a wire at such a distance from the outside coating of the jar, as the knob of the jar is from the prime conductor; then, on working the machine, you will find, that whenever a spark goes from the prime conductor to the wire of the jar, another spark passes from the outside coating of the jar to the knob of the wire that is presented to it; which shows that according as a quantity of electric fluid enters the jar, about an equal quantity of the electric fluid which belongs to the outside of the jar, leaves that outside. In this manner the jar becomes charged. If in this experiment the same fluid which goes from the prime conductor to the knob of the jar, came through it, and passed to the opposed knob, the jar could not possibly become charged.—When the jar is charged, if you present the pointed extremities of the discharging rod at a certain distance from the outside coating and from the knob of the jar, as shown in fig. 73., you will perceive (if the experiment be performed in the dark) both points illuminated, viz. the upper point with a little star, and the lower, B, with a brush of light, provided the jar has been charged po-

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sitively in the inside; but if the jar be charged negatively in the inside, (viz. by presenting its knob to the negative conductor) then the star and the brush will be reversed, viz. the brush will issue from the upper, and the star will appear on the lower, point. By this means the jar is silently discharged.

169. Dispose the apparatus as in the above-mentioned experiment, (160.) with the card; viz. lay a card upon the tablet E of the universal discharger, fig. 75., but with this difference, that instead of laying the extremities of both wires upon the same side of the card, one of them be placed under the card; then send a shock through the said wires, and it will be found that the electric fluid will run over that surface of the card, which is touched by the wire that communicates with the positive side of the jar; and in order to pass to the other wire, it will break a hole through the card just over the extremity of that other wire. The course of the electric fluid in this experiment may be seen either by the luminous track, if the experiment be performed in the dark, or by previously painting the card on both sides with vermilion and gum-water; for the passage of the electric fluid will leave a permanent dark track upon it.

170. Take a small coated phial, and by breathing upon its external uncoated part, render that part slightly damp; then holding it by its outside, present its knob to the prime conductor, while the machine is in action, and you will find that, after the phial has received a small charge, a beautiful brush of rays will proceed from the cork, which, after going a little way into the air, bends its course towards the outside coating of the phial. If the phial be charged negatively in the inside (viz. if its knob be presented to the insulated rubber), then the luminous brush will issue from the outside coating, and will proceed towards the cork or wire of the phial. In this experiment the outside of the phial must be damped to a certain degree, which experience only can teach.

171. Remove the circular board E from the universal discharger, fig. 75., fix the wires DC, DC, so that their knobs D, D, may be about two inches asunder, and upon the socket F fix a piece of wax-taper lighted, so that its flame may be midway between the two knobs D, D. This done, if you connect, by means of a chain or otherwise, the outside of a charged Leyden phial with one of the wires C, and bring the knob of the phial to the other wire C, you will observe that on making the discharge, which must pass from one of the knobs D to the other, the flame of the wax-taper is always driven in the direction of the electric fluid; that is, it will be blown upon the knob of that wire which communicates with the negative side of the phial.—In this experiment the phial must have a small charge, which experience will presently determine. With high charges the experiment does not succeed, because the charge passes too suddenly, and likewise because on approaching the phial to the wire, a considerable electrical atmosphere is formed round the knob of that wire, which disturbs the flame, &c.

172. If a Leyden phial be closely stopped, and a narrow and open tube, containing a drop of water, be passed through and cemented into its cork, it is evident that if the air within the jar be at all rarefied or condensed, the drop of water within the tube must be moved from its place. Now on charging this phial either positively or negatively in the inside, the water within the narrow tube will not be moved from its place; which shows that the charge does by no means displace the air. Nor will the water be moved on making the discharge, unless a spark happens to be between the inside coating and the wire, or between the various parts of the inside coating; for a spark always rarefies a little and displaces the air.

173. Take a naked phial, and for a coating on the outside stick a piece of tin-foil with a little wax, so that it may just adhere to the glass; and for an inside coating use small leaden shot, or quicksilver; lastly, insert a wire into the phial. This done, hold the phial, thus coated, by its outside, and charge it in the usual manner. When

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charged, turn it upside down, and pour its contents into an insulated cup for examination; also remove the outside coating. By this operation the phial does not lose its charge, and if the quicksilver or the shot which formed the inside coating be examined by means of an electrometer, it will be found slightly electrified, viz. as much as any other like insulated conductor that has been in contact with the prime conductor. Pour the same shot or quicksilver, or else some other quicksilver, again into the phial, and replace the outside coating; then touch the outside coating with one hand, and the inside with the other hand, by means of a wire, &c. and you will feel a shock, which will convince you that the phial had not lost its charge, and will at the same time prove that the charge does not reside in the coating.

The illustration which the preceding experiments afford to the theory of a single electric fluid is so obvious as to require no further explanation. A great many other experiments with the Leyden phial, which might here be added, are in general only variations of those which we have already described.

CHAPTER VII.

Of the various Sources of Electricity.

174. HITHERTO we have taken notice of one mode of producing electricity, namely, by means of friction; and have stated its properties, together with its most rational theory. But electricity is also produced by other means, which remain to be described, and which indeed are intimately concerned in several grand natural processes.

There is hardly an operation of nature which does not produce some electricity, or with which electricity does

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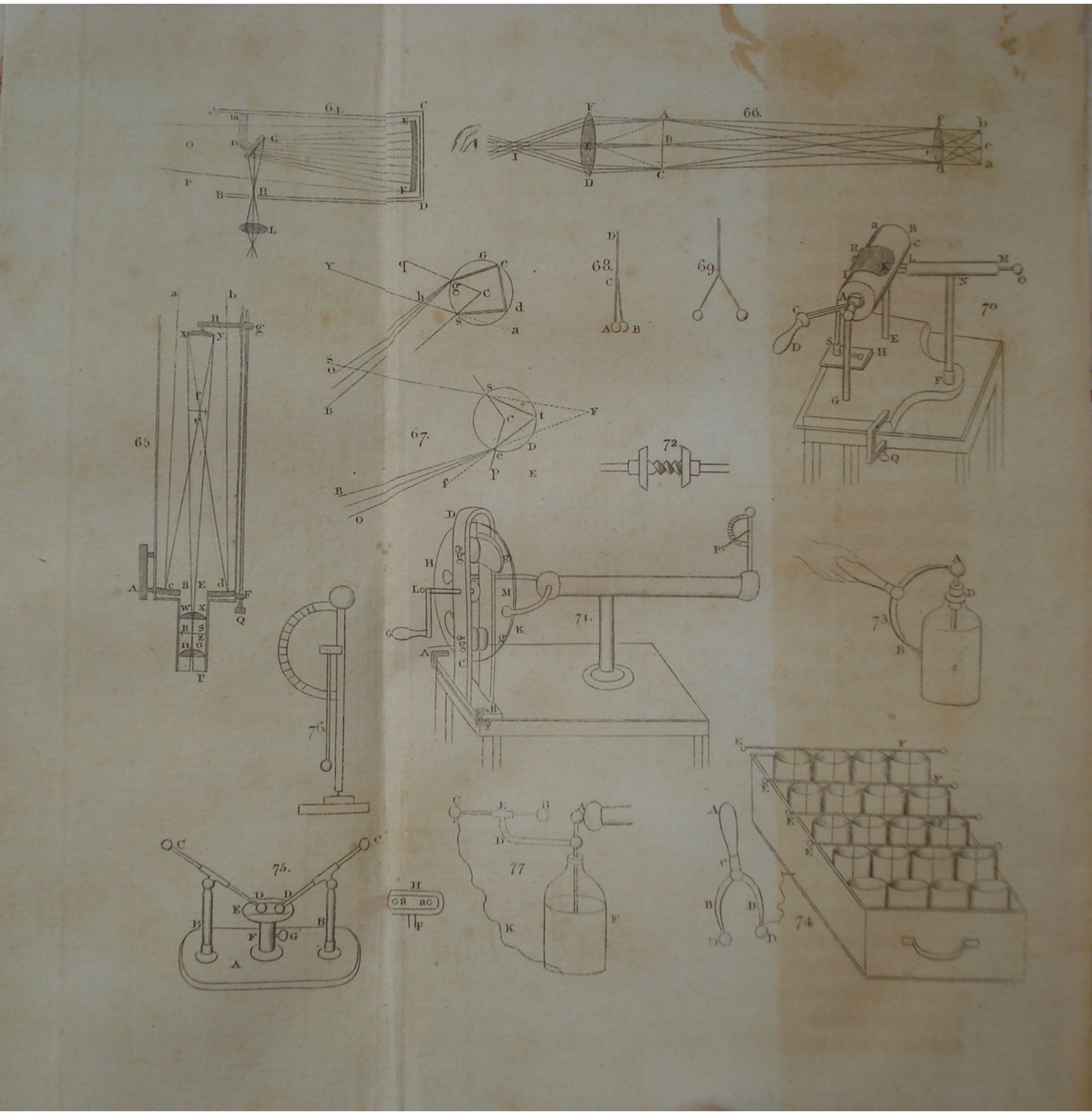

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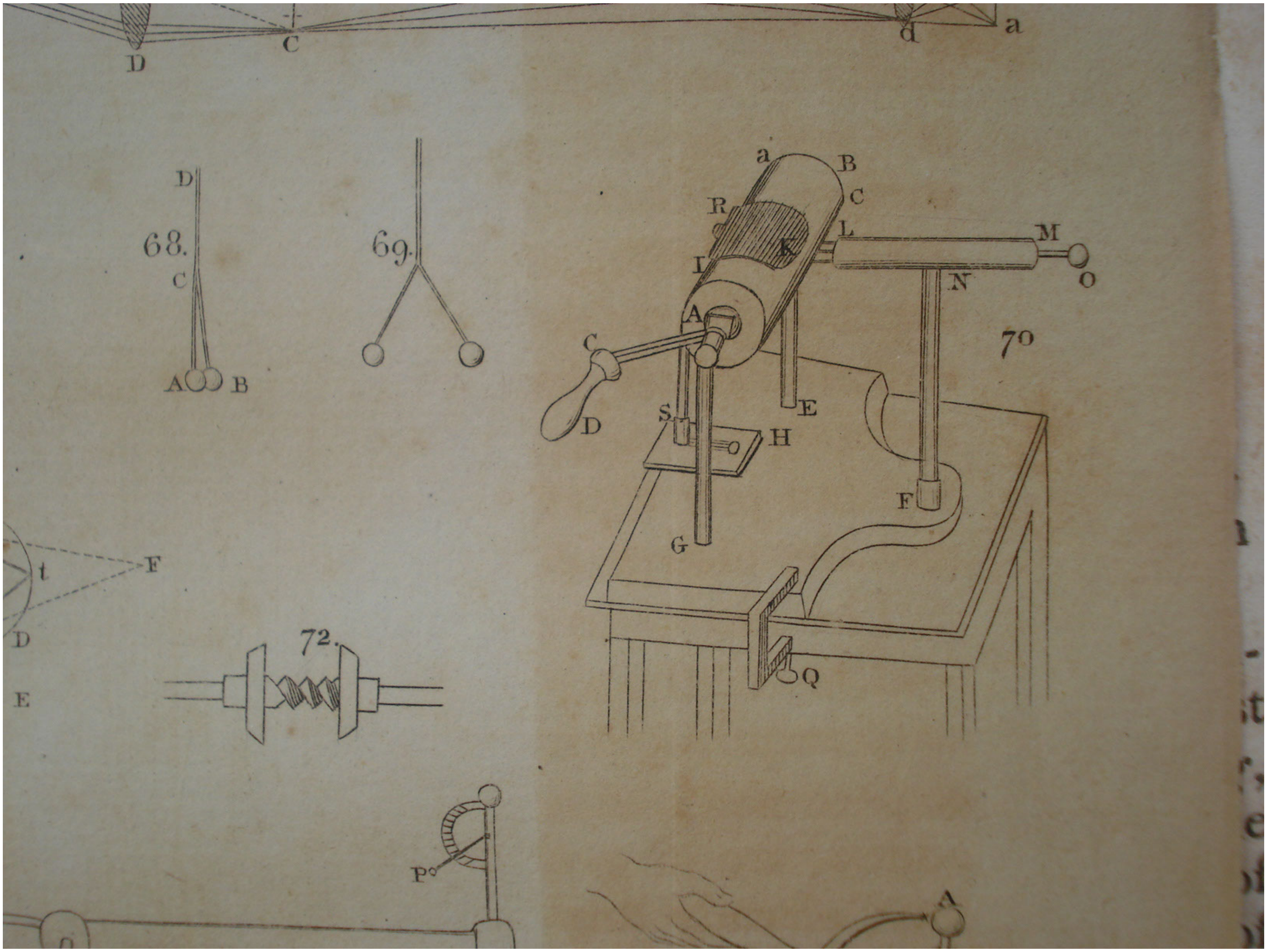

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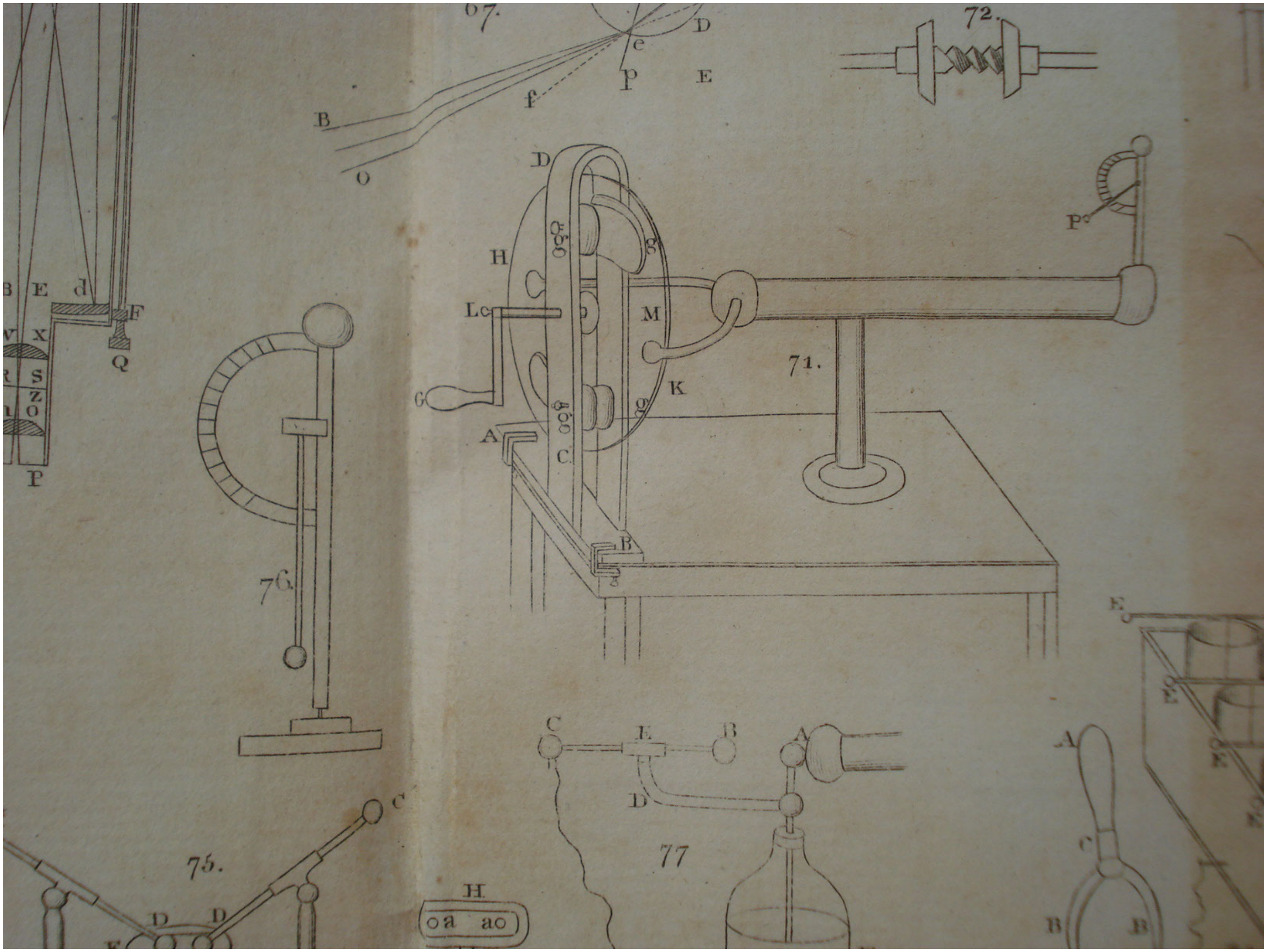

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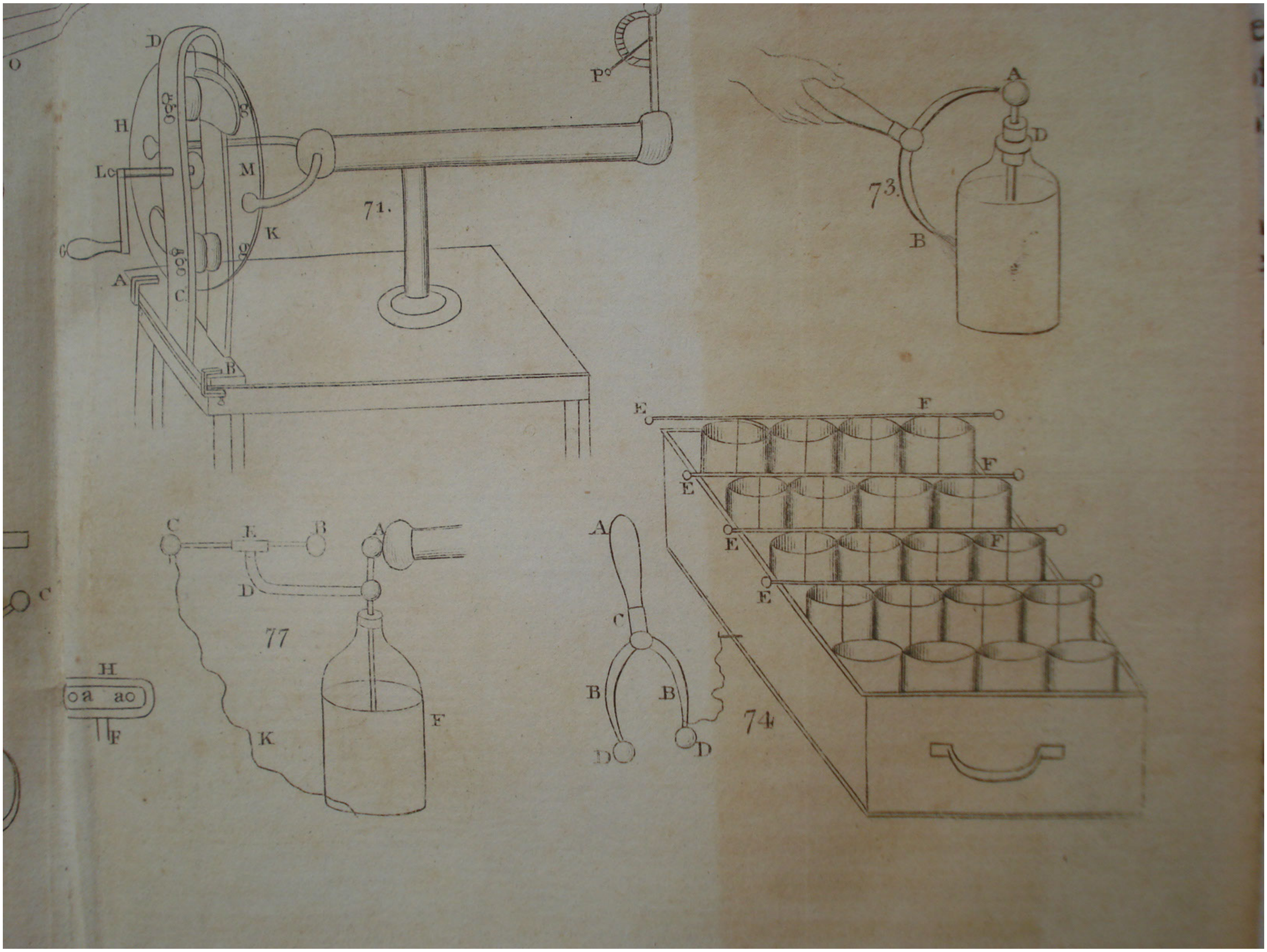

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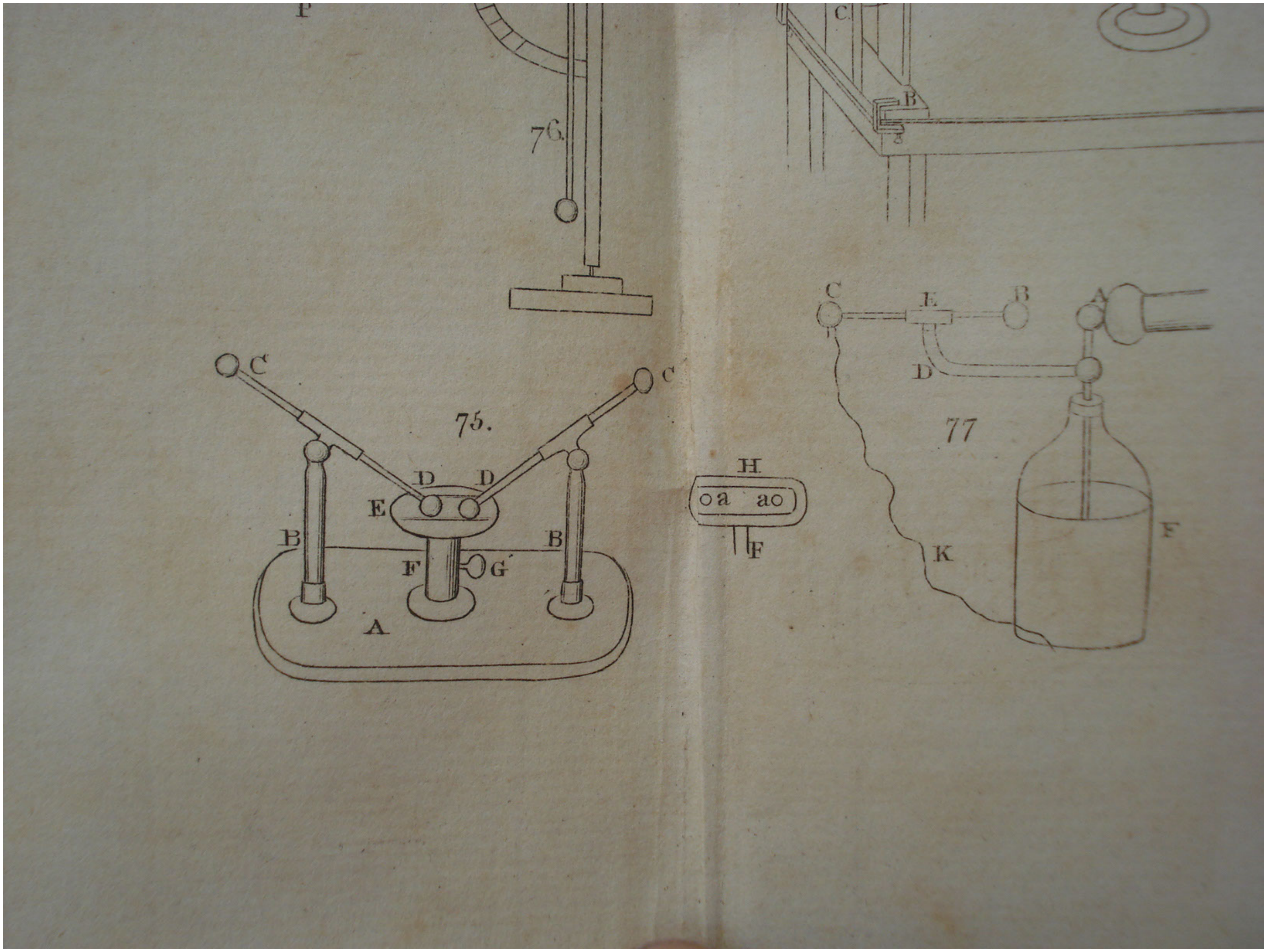

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not seem to be in some measure concerned. Probably all the different productions of electricity follow one general law; however, for the sake of perspicuity it will be necessary to specify those various sources, besides friction, and to reduce them to the following species.

1. Electricity is produced by the melting or by the coagulation after liquefaction, of certain substances.

2. It is produced by merely heating or cooling some particular bodies.

3. It is produced by evaporation and by the condensation of vapour.

4. It is to be found in the atmosphere at all times, more or less.

5. It is yielded by certain animals.

6. It is produced by the mere contact, or by the natural action of certain conducting bodies upon each other.

We shall describe those different sources of electricity in the following chapters; comprehending the first three under the title of *electricity produced by melting, heating, cooling, and evaporation;* the 4th under the title of *atmospherical electricity;* the 5th under the name of *animal electricity;* and the last under the appellation of *Galvanism*.

175. But previous to this it will be necessary to describe, in the present chapter, the principal methods that have been contrived for discovering the presence, and for ascertaining the quality, of very small quantities of electricity; for sometimes the electricity, which is produced by the above-mentioned sources, is so very small as to require the utmost attention and mechanical contrivance on the part of the philosopher.

The action of electric atmospheres is the principle which has furnished the methods of manifesting the presence of small quantities of electricity, viz. of such quantities as of themselves could not affect an electrometer sensibly.

Let an electrometer be affixed to an insulated metallic plate. Communicate some electricity to this plate, and the electrometer will diverge. In this state bring the plate near a conductor not insulated, and you will find that the electrometer collapses in proportion as you approach the plate to the uninsulated conductor. Remove the electrified plate, and the electrometer will again diverge to its former degree very nearly; which shows that by the

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vicinity of the uninsulated conducting body, which could easily acquire the contrary electricity, the intensity of the electricity in the electrified plate was diminished; or, which is the same thing, that the capacity of that plate for containing electricity was increased, because in that situation a greater quantity of electricity must be communicated to the plate, in order to raise the electrometer to the same height as when the plate is not opposed to an uninsulated conductor.

It easily follows, that according as the conductor which is opposed is larger or smaller, and also as it is nearer or further, so the capacity of the plate may be increased more or less.

Now if there be a source of electricity which, when communicated to an electrometer, is too weak to affect it; let an ample insulated plate be situated very near another plate not insulated, and in that state let the former plate communicate with the body which furnishes the weak electricity; and the plate so situated will acquire a considerable quantity of that electricity, which, whilst this plate is opposed to the other, will not affect the electrometer; but if afterwards the receiving plate be removed from the vicinity of the other plate, its capacity for containing electricity will be diminished, and of course the absorbed electricity will appear much stronger upon its surface, &c.—Such a receiving plate was called a *condenser* by Mr. Volta.

Further, it must be remarked that when a body is electrified, if an insulated plate be brought near it, and in that state be touched, for instance, with a finger, the plate will thereby acquire the contrary electricity. Now remove the finger, also remove the plate, and give its electricity to an insulated body, as to an electrometer, by touching it with that plate; then repeat the operation, viz. bring the same plate near the original electrified body, and touch it, by which means you can communicate to it as much electricity as before, which may also be communicated to the same electrometer; and thus by degrees the electrometer will be caused to diverge sufficiently; whereas the mere contact of the original electrified body might not be nearly sufficient to affect it sensibly. In this case the electricity which is communicated to the electrometer is evidently contrary to that of the original electrified body; viz. it will be positive if that was negative, and *vice versa*.

Upon this principle the electrophorus acts;* and upon this principle several machines have been contrived for rendering manifest a small quantity of electricity.†

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* See my Treatise on Electricity, 4th edition, vol. II. p. 40., and 244.

† Mr. Bennet's Doubler is an ingenious contrivance for the purpose of manifesting very small quantities of electricity, which acts upon the above-mentioned principle. It was afterwards improved

176. Before the year 1795, I contrived a machine for this purpose, to which, by way of distinction, I gave the name of *Multiplier of Electricity*, and which, after long use, seems (if the partiality for my own contrivance do not deceive me) to answer the purpose in a manner more commodious and much less equivocal than any other instrument of the kind. This machine is delineated in fig. 83.

QRS is the bottom board, upon which are steadily fixed on the glass sticks H G, two flat brass plates, A and C. B is a similar brass plate supported by a glass stick I, which is cemented into a hole made in the wooden lever KL. This lever moves round a steady pin or axis K, which is screwed tight in the bottom board. By moving this lever alternately from L to X, and back again, the plate B, with the lever, may be placed in the two situations, viz. the situation LIBK, and that which is shown by the dotted representation of the same. N is a thick brass wire fixed tight into the bottom board. O*m* is a crooked wire that proceeds from the brass socket on the back of the plate B.

There is likewise a fourth brass plate D, similar to the others, which is supported, not by glass, but by a wire; and this wire is screwed fast to an oblong piece of brass FP, which slides in a groove made for the purpose in the bottom board QRS, so that by applying a finger's nail to the notch at the end F, the sliding piece FP may be drawn out either entirely or to a certain length, and of course the plate D will be removed to any required distance from the plate C. When FP is pushed quite home, the plate D stands parallel to C, and at $\frac{1}{20}$th of an inch distance from it.

The parts of this instrument are so adjusted, that when the lever is in the situation of the shaded part of the figure (viz. is pushed as far as it can go towards Q), the plate B comes parallel to the plate A, and about $\frac{1}{20}$th of an inch distance from it. At the same time the extremity of the wire O*m* just touches the fixed wire N, and of course renders the plate B uninsulated. But as soon as the lever begins to move towards S, the communication of the plate B with the wire N, or with the ground, is interrupted, and B remains insulated. When the lever has been moved as far as it can go towards S, the wire *m* comes in contact with the plate C, as is shown by the dotted part of the figure. Then the two plates B and C communicate with each other, but they are otherwise insulated.

When this instrument is situated in the manner which is indicated by the shaded part of the figure, the plate A has its capacity for electricity increased by the proximity of the uninsulated plate

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by Mr. Nicholson. But in all its states it is apt to contract a certain permanent electricity, which renders its effect equivocal in most cases. See the Philosophical Transactions, vol. 77 and 78; also my Treatise on Electricity, 4th edition, vol. III. p. 76.

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B: hence A, if it be caused to touch a body weakly electrified, will acquire a greater quantity of electricity from it than it would otherwise do. Now suppose that A has acquired a small quantity of electricity, for instance, positive (since by changing the words positive for negative, and *vice versa*, the following explanation is applicable to the case in which A is electrified negatively); then B will acquire the negative electricity. On moving the lever L, the communication between B and the ground, or the wire N, is discontinued, and B remains insulated and electrified negatively. With this electricity B is carried towards C, until the wire *m* touches the plate C, and then the negative electricity of B will pass almost entirely to C, because the capacity of C for holding electricity is considerably increased by the proximity of the uninsulated plate D. If after this the lever be moved back to its first situation, B will be made negative a second time as before; and by pushing the lever again towards S, that second charge of negative electricity will be communicated from B to C. And thus by repeating the operation, a considerable quantity of electricity will be accumulated upon C. Then if the sliding piece FP be drawn out about one inch, the plate D will, of course, be removed as much from C: hence the capacity of C will be much diminished. Therefore, if an electrometer be brought into contact with it, the negative electricity, (viz. the electricity contrary to that of the original electrified body in question), will be manifested; whereas the electricity originally communicated to the plate A could perhaps not have affected an electrometer in any sensible degree.

The principal cause which renders this instrument certain in its effects, is, that all the residuum of electricity which can remain upon the plate A after the performance of an experiment, and after having touched that plate, is too inconsiderable to induce a contrary electricity in B; the electricity which is originally communicated to A, being not increased upon it in the course of the experiment.

CHAPTER VIII.

Of the Electricity which is produced by means of melting, heating, cooling, and evaporation.

177. IF sulphur be melted in an earthen vessel, and the whole be left to cool upon conductors; and if afterwards the sulphur, when cold, be taken out of the vessel, it will be found strongly electrical; but not at all so, if it be left to cool upon electrics.

If sulphur be melted in a glass vessel, and be left to cool, both the glass and the sulphur will acquire a strong electricity; the former positive, and the latter negative; and that will be the case whether they be left to cool upon electrics or upon conductors.

If melted sulphur be poured into a vessel of baked wood, it will acquire the negative, and the wood the positive, electricity; but if it be poured into sulphur, or rough glass, it will acquire no sensible degree of electricity.

Melted sulphur poured into a metal cup, and there left to cool, shows no signs of electricity whilst standing in the cup; but if they be separated, then they will both appear strongly electrified, the sulphur positive, and the cup negative. If the sulphur be replaced in the cup, every sign of electricity will vanish; but if, whilst separate, the electricity either of the cup or of the sulphur be taken off; then on being replaced they both will appear possessed of that electricity which has not been taken off.

Melted wax, being poured into glass or wood, acquires the negative electricity, and the glass or wood becomes positive. But sealing-wax poured into a sulphur vessel, acquires the positive electricity, and leaves the sulphur negative.

Chocolate fresh from the mill, as it cools in the tin pans in which it is received, becomes strongly electri-

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cal. When turned out of the pans, it retains this property during a certain time, but loses it presently by handling. By melting it again in an iron ladle, and pouring it into the tin pans as at first, you may renew its power once or twice; but when the mass becomes very dry and powdery in the ladle, the electricity is no longer revived by simple melting; but if then a little olive oil be added, and be mixed well with the chocolate in the ladle, and be afterwards poured into the tin pans, as at first, it will be found to have completely recovered its electrical power, which continues a considerable time.*

178. The property of becoming electrified merely by heating or cooling, was first observed in, and is eminently possessed by, a hard pellucid stone called *tourmalin*, which is generally of a deep red, or purple, or brown colour; which seldom, if ever, exceeds the size of a small walnut; and which is found in several parts of the East Indies, especially in the island of Ceylon; but on further examination it has been found that several other precious stones, and especially the Brasilian emerald, possess the like properties more or less: hence the following particulars, which have been principally observed with the tourmalin, must be understood to belong likewise to most other precious stones.

1. The tourmalin, while kept in the same temperature, shows no signs of electricity; but it will become electrical by increasing or diminishing its heat, and stronger in the latter circumstance than in the former.

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* Resinous or oleaginous electrics, when once excited, retain their electric power for a very considerable time, sometimes for several days. But that power gradually diminishes, and at last vanishes; nor do we know of any electric which retains the electric virtue as permanently as the magnet retains its magnetic power.

When a stick of glass, or of sulphur, and especially of sealing-wax, is broken into two pieces, the extremities which were contiguous, will generally be found electrified, one positive, and the other negative. This is probably occasioned by the rushing in of the air, which may produce a slight friction.

A very trifling alteration of temperature is often sufficient to produce the effect.

2. Its electricity does not appear all over its surface, but only on two opposite sides of it, which may be called its poles, and which always are in one right line with the centre of the stone, and in the direction of its strata; in which direction the stone is absolutely opake, though in the other it is semitransparent.

3. Whilst the tourmalin is heating, one of its sides (call it A) is electrified plus, or positive, and the other, B, minus; but when cooling, A is minus, and B is plus. Hence, if one side of the stone is heating, whilst the other is cooling, then both sides will acquire the same electricity; or if one side only changes its temperature, then that side only will appear electrified.

4. If this stone be heated, and suffered to cool without either of its sides being touched, then A will appear positive, and B negative, all the time of its heating and cooling.

5. This stone may be excited by means of friction like any other electric, and either of its sides, or both, may be rendered positive.

6. If the tourmalin be heated or cooled upon some other insulated body, that body will be found electrified as well as the stone; but it will be found possessed of the electricity contrary to that of the contiguous side of the stone.

7. The electricity of either side, or of both, may be reversed by heating or cooling the tourmalin in contact with various substances, such as the palm of the hand, a piece of metal, &c.

8. Those properties of the tourmalin are also observable in vacuo, but not so strong as in the open air.

9. If a tourmalin be cut into several parts, each piece will have its positive and negative poles, corresponding to the positive and negative sides of the original stone.

10. If this stone be covered all over with some electric substance, such as sealing-wax, oil, &c. it will in general show the same properties as without it.

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11. A vivid light appears upon the tourmalin, whilst heating in the dark, and by a little attention one may be easily enabled by this light to distinguish which side of the stone is positive, and which negative. Sometimes, when the stone is strongly excited, pretty strong flashes may be seen in the dark, to go from the positive to the negative side of it.

12. Lastly, it has been found that with respect to the electric properties, the tourmalin is sometimes injured by the action of a strong fire, at other times is improved, and sometimes is not at all altered by it.

179. The evaporation of water, as also of some other fluids, produces electricity, viz. those bodies from which the water has departed, will remain in a negative state of electricity, indicating that the water by its conversion into vapour, has its capacity for the electric fluid increased, as it has its capacity increased for containing heat.* But though the effect is in general such as has been mentioned above, yet there are two exceptions which involve the subject in some difficulty, and which will require further experiments and consideration.

The exceptions are, 1st, that if water be evaporated by being put in contact with a red-hot piece or pieces of very rusty iron, it will leave the iron electrified positively; whereas, if the iron be not rusty, the evaporation of the water from its surface will leave it electrified negatively. 2dly, If water be evaporated by throwing into it impure red-hot glass (such as the green glass of common bottles) the vessel, or the remaining water, will be electrified positively.

This curious production of electricity by evaporation, as also the production of electricity by the condensation of vapour, may be easily observed in the following manner:

* Mr. Volta, who made this remarkable discovery, likewise observed, that the simple combustion of coals, as also the effervescence of iron filings and diluted sulphuric acid produce the same effect; which is, in all probability, owing to the evaporation which attends those processes.

Place a metallic cup, or a pewter plate, upon an insulating stand, and connect a sensible electrometer with it. Also place one or two lighted coals in the cup or plate; then pour a little water at once upon the coal or coals, which will produce a quick evaporation, accompanied with a great hissing noise, and at the same time the electrometer will diverge with negative electricity.

If the steam, which issues copiously from water quickly boiling, be received under a pretty large and insulated metallic plate, that plate, by the condensation of the steam upon it, will be electrified positively, as may be ascertained merely by connecting a sensible electrometer with it.

On throwing a variety of other substances upon actually burning, or only hot and insulated, coals, the coals, &c. either show negative electricity, or no electricity at all. Either spirit of wine, or ether when thus treated, leave the coals negative, but if, (the coals being sufficiently hot) the spirit of wine or the ether take fire and burn in the usual way, then no electricity is produced.

CHAPTER IX.

Atmospherical Electricity.

180. The memorable year 1752 produced the remarkable discovery of the identity of lightning and electricity, which, previous to that year, had only been suspected by philosophers.

The similarity of lightning to artificial electricity is not to be remarked in a few appearances only, but is observable throughout all their numerous effects; and there is not a single phenomenon of the one, which may not be imitated by the other. Lightning destroys edifices, animals, trees, &c.—Lightning goes through the best conductors in its way; and if its passage be obstructed by electrics, or less perfect conductors, it rends and disperses them in every direction;—lightning burns combustible bodies;—it melts metals;—a stroke of lightning often disturbs the virtue of a magnet, and gives polarity to ferruginous substances; and all these effects

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may be produced upon a much smaller scale by means of artificial electricity. But independent of the great similarity between the effects of lightning and those of electricity, what fully proves their identity, is, that the matter of lightning may be actually brought down from the clouds by means of insulated metallic rods; or of electrical kites, and with it any known electrical experiment may be performed.

Clouds, as well as rain, snow, and hail, which fall from them, also fogs, are almost always electrified, but oftener negatively than positively; and the lightning, accompanied with the thunder, is the effect of the electricity, which, darting from a cloud, or a number of clouds highly electrified, strikes into another cloud, or else upon terrestrial objects; in which case it prefers the loftiest, most pointed, and best conducting objects; and by this stroke it produces all those dreadful effects, which are known to be produced by lightning.

The air, at some distance from houses, trees, masts of ships, &c. is generally electrified almost always positively, especially in frosty, clear, or foggy weather; but how the air, the fogs, and the clouds become electrified, has not yet been fully and clearly ascertained. We shall in this chapter state the principal facts which have been observed with respect to the atmospherical electricity, and subjoin the most plausible explanation, together with the advantage which is derived from the knowledge of the subject.

187. I shall however previously describe such instruments as are most useful for discovering this electricity.

My electrometer in a phial, which has been already described (153.) is the best portable instrument for this purpose; for if you hold this electrometer by its lower part, and raise it just above the level of your head in the open air, when the air is strongly electrified, or in a fog, or when electrified clouds are over head, and sometimes, even when they are a little way above the horizon; the divergency of the electrometer will announce the presence of electricity, and by the approach of an excited stick of sealing-wax, or of any other electric, you may easily determine whether the electricity be positive or negative; observing that the electricity of the

electrometer in this case is the contrary of that of the clouds or fog: but if the electrometer be electrified by the rain, or snow, or hail, falling upon it; then the electricity of the rain, &c. is the same as that of the electrometer; for in the latter case the electrometer is electrified by the contact, but in the former case it is electrified by the action of electric atmosphere. Art. 130 and 136.

When the electricity of the air is not so strong as to be discovered by this instrument, then an electrometer must be extended further out into the air. For this purpose I have long used the following most commodious instrument or atmospherical electrometer.

AB, fig. 84., is a common jointed fishing-rod, wanting the last or smallest joint. From the extremity of this rod proceeds a slender glass tube or glass stick C, which is covered with sealing-wax, and has a cork D at its extremity, to which a cork-ball electrometer, E, is suspended. HGI is a piece of common packthread, fastened to the rod at A, and supported at G by a short string FG. At the extremity I of the packthread, a pin, or pointed wire, is fastened, which, when pushed into the cork D, renders the electrometer E uninsulated.

When I wish to observe the electricity of the atmosphere with this instrument, I thrust the pin I into the cork D, and holding the rod by its lower end A, I project it out from an upper window, raising the end B with the electrometer, so as to make an angle of about 50° or 60°, with the horizon. In this situation I keep the instrument for a few seconds; then pulling the packthread at H, I disengage the pin from the cork D; which operation causes the string to drop in the dotted situation HK, and leaves the electrometer possessed of the electricity contrary to that of the atmosphere.—This done, I draw the instrument within the room, and examine the quality of the electricity, without any obstruction either from wind or darkness.

If any person wish to observe the electricity of the rain, he may either occasionally use, or have always fixed, a rod or an assemblage of wires round a rod covered with sealing-wax, cemented into a glass tube, by which it may be either held in the hand occasionally, or may be permanently fixed within a room, and projecting about two or three feet out of a window; for which purpose either the window must be opened occasionally, or the rod must pass through a hole sufficiently large. To that end of this rod which is within the room, an electrometer must be attached, and it will frequently happen, that when it rains, and the rain falls upon the projecting part of the rod, the electrometer at its internal extremity is electrified.

But an insulated wooden rod, with a wire round it, and projecting about 15 or 16 feet above the house, will answer every purpose; for a wire proceeding from this rod may be made to communicate with an electrometer within the room, where the intensity as well as the quality of the electricity may be observed. Such a rod how-

ever is very dangerous in time of a thunder storm. In order to avoid the danger, a conducting communication, viz. a ball of brass should be placed at about two inches distance from the rod, and a thick wire should be carried from this ball to the ground or to the pump, &c. in order that if a large quantity of electricity from a cloud strike the rod, that electricity may be conveyed by the wire to the ground, without hurting the by-standers.*

When the electricity of the air, or rain, &c. is too weak to be discovered by those instruments, then my multiplier may be used in conjunction with any of them; or the electricity of the atmosphere may be discovered by means of an electrical kite; which is nothing more than a common paper kite, such as is used by children, only having a string which is rendered a better conductor by having a slender wire through it. The paper of the kite should likewise be covered with drying linseed oil, in order to defend it from the rain.

A kite of about four feet in height is the most commodious for this purpose. The string is the most material part of this apparatus; for according as the string is longer or shorter, a better or a worse conductor, so is the electricity which is brought down by it stronger or weaker. The kite only serves to keep the string up into the atmosphere. After a variety of trials the best string proved to be one which I made by twisting a copper thread, (viz. such as is used for trimmings, &c. in imitation of gold thread, which is nothing more than silk or linen thread covered over with a thin lamina of copper) with two very thin threads of twine.

When the kite is flying, the lower part of the string must be insulated by means of a silk string of about two or three feet in length, or by means of a glass stick, &c.; then at the lower extremity of the string you may not only electrify an electrometer, but you may also draw sparks, or charge a Leyden phial, &c. and that at every hour of the day or night, and at all times of the year, and will seldom fail.—This kite is dangerous during a storm.

182. It appears, 1. That there is in the atmosphere, at all times, a quantity of electricity; for whenever I use the above-described fishing-rod electrometer in an open situation, it always acquires some electricity, and that electricity is always of the same kind, viz. negative; which shows that the electricity of the air or of fogs, is

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* For the construction of such a rod, see Mr. J. Read's *Summary View of the Spontaneous Electricity of the Earth and Atmosphere.* London, 1793

The famous Fr. Beccaria used a long cord extended in the atmosphere between two houses. See his Electricity.

almost always positive, except when the instrument is influenced by clouds near the zenith.

2. That the strongest electricity is observable in thick fogs, and likewise in frosty weather; but the weakest, when the weather is cloudy, warm, and very near raining; but it does not seem to be less at night than in the day time.

3. That in a more elevated place the electricity is generally stronger than in a lower one. Thus I have often observed the electrometer to diverge more in the iron than in the stone gallery on the outside of the cupola of St. Paul's cathedral.

4. That the rain, snow, and hail, are more or less, but almost always electrified, much more frequently with negative than with positive electricity.

After a vast number of experiments with electrical kites during upwards of two years, I was enabled to form the following conclusions:

1. The air appears to be electrified at all times; its electricity is constantly positive, whether by day or night, and much stronger in frosty than in warm weather. My experiments have been made in every degree of temperature between 15° and 80°.

2. The presence of clouds generally lessens the electricity of the kite; sometimes it has no effect upon it, and seldom increases it.

3. During rain the electricity of the kite is generally negative, and seldom positive.

4. The aurora borealis, or northern light, does not appear to affect the electricity of the kite.

5. The spark taken from the string of the kite, or from any insulated conductor which is connected with it, especially when it does not rain, is very seldom longer than a quarter of an inch; but it is remarkably pungent; so that the operator will frequently feel the effect of it even in his legs; it appearing more like the discharge of an electric jar than like the spark which is taken from the prime conductor of an electrical machine.

6. The electricity which is brought down by the string of the kite is, upon the whole, stronger or weaker, according as the string is longer or shorter; but it does not keep any exact proportion to it; for instance, the electricity from a string of 100 yards may raise the index of a quadrant electrometer 20°, whereas with double that length of string the index will not rise higher than about 25°.

7. When the weather is damp, and the electricity is pretty strong, the index of the electrometer, after taking a spark from

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the string, or presenting the knob of a coated phial to it, rises with surprising quickness to its usual degree; but in dry and warm weather, it rises remarkably slowly.

183. After the discovery of the identity of electricity and the matter of lightning, as also of the constant existence of electricity in the atmosphere, philosophers endeavoured to attribute some other atmospherical and even terrestrial phenomena to the agency of electricity. Thus the ascensions, commonly called *falling stars* or *shooting stars*, meteors, waterspouts, hurricanes, whirlwinds, &c. have been considered by several persons as being electrical phenomena; but of this we have no positive proofs.

The *aurora borealis*, or northern light, seems most likely to be an electrical phenomenon; and this on two accounts, viz. first because a magnetic needle appears a little disturbed at the time of a strong aurora borealis; and secondly, because the aurora borealis may be partly imitated by means of artificial electricity.*

Take a glass phial nearly of the shape and size of a Florence flask; fix a stop-cock, or a valve to its neck, and exhaust it as much as you can by means of a good air-pump. If then this glass be rubbed after the manner commonly used for exciting electrics, it will appear luminous within, being full of a flashing light, which plainly resembles the *aurora borealis*. This phial may also be rendered luminous, if, holding it by either end, you bring its other end to the prime conductor; in this case all the cavity of the glass will instantly appear full of light, which may be seen flashing in it for a considerable time after it has been removed from the prime

* The *aurora borealis* is a phenomenon pretty well known to the present generation throughout Europe at least. It is a lambent or flashing light, which consists of separate coruscations seen at night in some periods more often than in others. They dart quickly from one part of the sky to another; they have different intensities and different tints. Sometimes those coruscations, when strong, are accompanied with a sort of crackling noise distinctly audible, as I remember to have heard it more than once.

conductor, especially if it be touched with the hand. This effect is easily deduced from the conducting nature of the vacuum, and from the charging and discharging of the glass.

184. The most plausible mode of accounting for the electricity which is constantly to be observed in the atmosphere, and which accompanies the clouds, the fogs, the rain, or that of thunder storms, is to derive it from the evaporation of water, and from the condensation of vapours. For though the electricity which is thus produced, may at first sight appear too small; yet if we consider that those processes are continually carried on, both upon the surface of the earth and in the atmosphere, we may easily acknowledge the sufficiency of it.

When the vapours depart from the earth, they carry away a much greater quantity of the electric fluid, than they had when in the form of water, and which they have derived from the earth. Now if those vapours, as they ascend in the atmosphere, become more rarefied, then, as they have no bodies at hand from which they can derive the electric fluid, which is required for their increased capacity, they must appear electrified negatively. On the contrary, if those vapours are condensed, then their capacity for the electric fluid being diminished, they must appear electrified positively. Besides, a cloud highly electrified may easily induce the contrary electricity in another contiguous cloud. From those causes a variety of particular accumulations of positive or negative electricity, or of changes from the one to the other may be easily conceived, apparently sufficient to account for the phenomena of atmospherical electricity.

185. One of the greatest advantages which mankind has derived from the knowledge of this branch of philosophy, is a defence for houses, ships, &c. against the fatal effects of the lightning. It was proposed by Dr. Franklin to erect an iron rod, or a wire of any metal on the top of a house, and to carry the communication by means of good conductors of electricity, from that rod down to the ground; for since the lightning generally

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strikes the most elevated conductors, through which it passes to the earth, it was natural to suppose that the house thus furnished with a conductor, would be defended from the pernicious effects of lightning. This wise proposal was generally adopted, and its usefulness has been confirmed by innumerable cases, especially in warm climates, which are much more subject to thunder storms.

The usefulness of conductors to defend buildings from the effects of the lightning, has been universally acknowledged; but the proper form of those conductors, especially with respect to their terminations, has been the cause of much controversy. It was objected to their having a pointed termination, that a pointed body can attract the electric fluid from a greater distance than a blunt termination, and therefore it would invite the lightning where otherwise the lightning would not go. To this it was replied, that though the point will attract the electric fluid from a greater distance, yet it will attract it in a stream, viz. by degrees, and not in a full body as a knob would do; by which means the force of the lightning will be diminished, and in certain cases a full stroke may thereby be entirely averted. In short, after a great variety of arguments and experiments, the best construction of such conductors seems to be as follows:*

It should consist of a rod of iron, or of other metal, about three quarters of an inch thick, fastened to the wall of the building, not by iron clamps, but by wooden ones. The rod should be uninterrupted from the top of the building to the ground; or if it consist of various pieces, care must be had to join the pieces as perfectly as possible. If this conductor stood quite detached

* See what relates to the conductors of lightning in the Philosophical Transactions for the year 1777, and ten or twelve following years; also see Earl Stanhope's Principles of Electricity, London 1779, and my Treatise on Electricity, 4th edition, vol. II. p. 207.

from the building, and supported by pieces of wood at the distance of one or two feet from the wall, it would be better for common edifices; but it is particularly advisable for gunpowder magazines, gunpowder mills, and all such buildings as contain combustibles ready to take fire. The upper end of the conductor should terminate in one or more sharp points; which, if the conductor be of iron, ought to be gilt, in order to prevent the rust or the oxigenation. This sharp end should be elevated above the highest part of the building (as above a stack of chimneys, to which it may be fastened) at least five or six feet. The lower end of the conductor should be driven five or six feet into the ground, and in a direction leading from the foundation; or it would be better to connect it with the nearest piece of water.

For an edifice of a moderate size, one of those conductors is perhaps sufficient; but a large building ought to have two, or three, or more conductors at its most distant parts.

On board of ships a chain has often been used on account of its pliableness; but in several cases the chain has been actually broken by the lightning, in consequence of the obstruction which the electric fluid meets with in going through the various links; hence, instead of a chain, a copper wire about one third part of an inch thick, is now more commonly used. One of those wires should be elevated two or three feet above the highest mast in the vessel; this should be continued down along the mast as far as the deck, where, by bending, it should be adapted to the surface of such parts as may be more convenient; and by continuing it down the side of the vessel, it should always be made to communicate with the water.

With regard to personal security in time of a thunder storm, if a person be in a house which is not furnished with a conductor, it is advisable not to stand near any metallic articles, viz. near gilt frames, chimney-grates, bell-wires, iron casements, and the like. In the middle of a room, upon a dry chair, or table, or mattresses, or

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other insulating articles, is the safest situation. Should a storm happen when a person is in the open fields, and far from any building, the best thing he can do is to retire within a small distance of the highest tree or trees he can get at; he must not, however, go quite near them, but he should stop at about fifteen or twenty feet from their outermost branches; for if the lightning happen to strike about the place, it will in all probability strike the trees in preference to any other much lower object; and if a tree happen to be split, the person will be safe enough at that distance from it.

CHAPTER X.

Of Animal Electricity.

186. UNDER this title we shall take notice of that electricity only which is produced from the animal itself, in consequence of its particular organization, and not that which is produced by the application of metallic substances to animals.

Three fishes have hitherto been discovered to have, whilst living, the singular property of giving shocks analogous to those of artificial electricity; namely, the *torpedo*, the *gymnotus electricus*, and the *silurus electricus*.* Those animals belong to three different orders of fish; and the few particulars, which they seem to have

* Nature seems to have given those fishes this singular power of giving the shock for the purpose of securing their prey, by which they must subsist; and perhaps likewise for the purpose of repelling larger animals, which might otherwise annoy them.

The ancients considered the shocks of the torpedo as capable of curing various disorders; and a modern philosopher will hardly hesitate to credit their assertions, since electricity has been found to be a useful remedy in several cases.

in common, are the power of giving the shock; an organ in their bodies, called the *electric organ*, which is in all probability employed by those animals for the exertion of that power; a smooth skin without scales; and some spots here and there on the surfaces of their bodies.

187. The torpedo, which belongs to the order of *rays*, is a flat fish, very seldom twenty inches long, weighing not above a few pounds when full grown, and is pretty common in various parts of the sea-coast of Europe. The electric organs of this animal are two in number, and are placed one on each side of the cranium and gills, reaching from that place as far as the semicircular cartilages of each great fin, and extending longitudinally from the anterior extremity of the animal to the transverse cartilage which divides the thorax from the abdomen. In those places they fill up the whole thickness of the animal from the lower to the upper surface, and are covered by the common skin of the body, under which, however, are two thin membranes or *fasciæ*. The length of each organ is somewhat less than one third part of the whole length of the animal. Each organ consists of perpendicular columns, reaching from the under to the upper surface of the body, and varying in length according to the various thickness of the fish in various parts. The number of those columns is not constant, differing in different torpedoes, and likewise in different ages of the animals. In a very large torpedo, one electric organ was found to consist of 1182 columns. The greatest number of those columns are either irregular hexagons, or irregular pentagons, but their figure is by no means constant. Their diameters are generally equal to one fifth part of an inch.

The above mentioned electric organs seem to be the only parts employed to produce the shock;* the rest of

* The manner in which the electric fluid is accumulated or generated by those organs, is by no means understood, but the subject of the next chapter may probably throw much light upon it.

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the animal appearing to be merely the conductor of that shock, as parts adjacent to the electric organs; and, in fact, the animal has been found to be a conductor of artificial electricity. The two great lateral fins, which bound the electric organs laterally, are the best conductors.

If the torpedo, whilst standing in water, or out of the water, but not insulated, be touched with one hand, it generally communicates a trembling motion or slight shock to the hand; but this sensation is felt in the fingers of that hand only. If the torpedo be touched with both hands at the same time, one hand being applied to its under, and the other to its upper, surface, a shock i that case will be received, which is exactly like that which is occasioned by the Leyden phial. When the hand touches the fish on its opposite surfaces, and just over the electric organs, then the shock is the strongest; but if the hands be placed upon other parts of the opposite surfaces, the shocks are somewhat weaker; and no shock at all is felt when the hands are both placed upon the electric organs of the same surface; which shows that the upper and lower surfaces of the electric organs are in opposite states of electricity, answering to the *plus* and *minus* sides of a Leyden phial. When the fish is touched by both hands on the same surface, and the hands are not placed exactly on the electric organs, a shock, though weak, is still received; but in this case the opposite power of the other surface of the animal seems to be conducted over the skin.

The shock which is given by the torpedo, when standing in air, is about four times as strong as when standing in water; and when the animal is touched on both surfaces by the same hand, the thumb being applied to one surface, and the middle finger to the opposite surface, the shock is felt much stronger than when the circuit is formed by the application of both hands. Sometimes the torpedo gives the shocks so quickly one after the other, that scarcely two seconds elapse between them; and when, instead of a strong determinate shock, it

communicates only a *torpor*, that sensation is naturally attributed to the successive and quick discharge of a great many consecutive shocks.

This power of the torpedo is conducted by the same substances which conduct artificial electricity, and is intercepted by the same substances which are nonconductors of electricity: hence, if the animal, instead of being touched immediately by the hands, be touched by non-electrics, as wires, wet cords, &c. held in the hands of the experimenter, the shock will be communicated through them. The circuit may also be formed by several persons joining hands, and the shock will be felt by them all at the same time. If, when the animal is in water, the hands be put in the same water, a shock will also be felt, which will be stronger if one of the hands touch the fish, whilst the other is kept in the water at a distance from it.

The shock of the torpedo cannot pass through the least interruption of continuity: thus it will not be conducted by a chain, nor will it pass through the air from one conductor to the other, when the distance is even less than the 200th part of an inch; consequently no spark was ever observed to accompany it.

No electric attraction or repulsion was ever observed to be produced by the torpedo; nor indeed by any of the electric fishes, though several experiments have been instituted expressly for that purpose.

These shocks of the torpedo seem to depend on the will of the animal; for each effort is accompanied with a depression of its eyes, by which even his attempts to give it to non-conductors may be observed. It is not known whether both electric organs must always act together, or one of them only, may be occasionally put in action by the will of the animal.

Almost all those effects of the torpedo may be imitated by means of a large electrical battery weakly charged.*

188. The gymnotus electricus has been frequently called *electrical eel*, on account of its bearing some resemblance to the common eel. The gymnotus is found pretty frequently in the great rivers of South America. Its usual length is about three feet; but some of them have been said to be so large as to be able to strike a man dead with their electric shock. A few of those animals, about three feet long, were brought alive to England about thirty years ago, and a great many experiments were made with them.

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* See Mr. Walsh's Paper in the Phil. Trans. vol. 63.

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A gymnotus of three feet in length generally is between 10 and 14 inches in circumference at the thickest part of its body. The electric power of this animal being much greater than that of the torpedo, its electric organs are accordingly much larger, and indeed that part of its body which contains most of the animal parts that are common to the same order of fishes, is considerably smaller than that which is subservient to the electric power, though the latter must naturally derive nourishment and action from the former. The head of the animal is large, broad, flat, smooth, and impressed with various small holes. The mouth is rather large, but the jaws have no teeth, so that the animal lives by suction, or by swallowing the food entire. The eyes are small, flattish, and of a bluish colour, placed a little way behind the nostrils. The body is large, thick, and roundish, for a considerable distance from the head, and then diminishes gradually. The whole body, from a few inches below the head, is distinguished into four longitudinal parts, clearly divided from each other by lines. The *carina* begins a few inches below the head, and widening as it proceeds, reaches as far as the tail, where it is thinnest. It has two pectoral fins, and the *anus* is situated on the under part, more forward than those fins, and of course not far distant from the *rostrum*.

This animal has two pairs of electric organs, one pair being larger than the other, and occupying most of the longitudinal parts of the body. They are divided from each other by peculiar membranes.

The nerves which go to the electric organs of the gymnotus, as well as of the torpedo, are much larger than those which supply any other part of the body. The electric organs of the gymnotus are supplied with nerves from the spinal marrow, and they come out in pairs between the vertebræ of the spine.

The gymnotus possesses all the electric properties of the torpedo, but in a superior degree. His shock is conducted by conductors of electricity; it is communicated through water, &c. The strongest shock is received

when, the animal standing out of the water, you apply one hand towards the tail, and the other towards the head of the animal. In this manner I often received shocks from one of those animals, which I felt not only in my arms, but very forcibly even in my chest. If the animal be touched with one hand only, then a kind of tremor is felt in that single hand, which, though stronger, is, however, perfectly analogous to that which is given by the torpedo, when touched in the like manner.

This power of the gymnotus is likewise depending on the will of the animal, so that sometimes he gives strong shocks, and at other times very weak ones. He gives the strongest shocks when provoked by being frequently and roughly touched.

When small fishes are put into the water, where the gymnotus is, they are frequently stunned, and are either effectually or apparently killed.

The strongest shocks of the gymnoti, which were exhibited in London, would pass through a very short interruption of continuity in the circuit. They could be conveyed by a short chain when stretched, so as to bring the links into a more perfect contact. When the interruption was formed by the incision made with a penknife on a slip of tin-foil that was pasted upon glass, the shock in passing through that interruption, showed a small but vivid spark, plainly visible in a dark room.

This animal showed a peculiar property, namely that of knowing when he could, and when he could not, give the shock; for if nonconductors or interrupted circuits were placed in the water, he would not approach them; but as soon as the circuit was completed, he would approach the extremities of that circuit, and immediately give the shock.*

189. The third fish which is known to have the power of giving the shock, is found in the rivers of Africa; but we have a very imperfect account of its properties.†

This animal belongs to the order which the naturalists call *silurus;* hence its name is *silurus electricus*. The length of some of those fishes has been found to exceed 20 inches.

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* See my Treatise on Electricity, 4th edition, vol. II. p. 309.

† Messrs. Adanson and Forskal make a short mention of it; and Mr. Brussonet describes it under the French name of *le Trembleur*, in the *Hist. de l'Acad. Royale des Sciences*, for 1782.

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The body of the silurus electricus is oblong, smooth, and without scales; being rather large, and flattened towards its anterior part. The eyes are of a middle size, and are covered by the skin, which envelopes the whole head. Each jaw is armed with a great number of small teeth. About the mouth it has six filamentous appendices, viz. four from the under lip, and two from the upper; the two external ones, or furthermost from the mouth on the upper lip, are the longest. The colour of the body is grayish, and towards the tail it has some blackish spots.

The electric organ seems to be towards the tail, where the skin is thicker than on the rest of the body, and a whitish fibrous substance, which is probably the electric organ, has been distinguished under it.

It is said that the silurus electricus has the property of giving a shock or benumbing sensation, like the torpedo, and that this shock is communicated through substances that are conductors of electricity. No other particular seems to be known concerning it.*

* A fourth fish, said to give shocks like the above-mentioned, was found on the coast of Johanna, one of the Comoro islands, in lat. 12° 13′ south, by lieutenant William Patterson, and an imperfect account of it is given in the Phil. Trans. vol. 76.

"The fish is described to be 7 inches long, 2½ inches broad, has a long projecting mouth, and seems of the genus Tetrodon. The back of the fish is a dark brown colour, the belly part of sea green, the sides yellow, and the fins and tail of a sandy green. The body is interspersed with red, green, and white spots, the white ones particularly bright; the eyes large, the iris red, its outer edge tinged with yellow."

Whilst this fish is living, strong shocks, like electrical shocks, are felt by a person who attempts to hold it between his hands. Three persons only are mentioned in the account as having experienced this property of one of those fishes; but the want of opportunity prevented the trial of further experiments.

CHAPTER XI.

Of Galvanism.

190. IN the year 1791, a very remarkable discovery made by Dr. Galvani of Bologna was announced to the scientific world in a publication entitled, *Aloysii Galvani de Viribus Electricitatis in motu musculari Commentarius.*

The discoveries of Dr. Galvani were made principally with dead frogs. He in the first place discovered that a frog dead and skinned, is capable of having its muscles brought into action by means of electricity, even in exceedingly small quantities.

Secondly, that independent of any apparent electricity, the same motions may be produced in the dead animal, or even in a detached limb, merely by making a communication between the nerves and the muscles, with substances that are conductors of electricity. If the circuit of communication consist of nonconductors of electricity, as glass, sealing-wax, and the like, no motion will take place.—The like experiments were also successfully instituted upon other animals; and as the power seemed to be inherent in the animal parts, those experiments, or the power which produces the motion of the muscles in those experiments, was denominated *animal electricity*. But it being now fully ascertained, that by the mere contact of metallic and other conducting substances, some electricity is generated, it is evident that the muscular motions in the above-mentioned experiments are produced by that electricity; hence we have confined the *name of animal electricity* to denote the power of the fishes which give the shock, &c. as described in the preceding chapter. And, at least for the present, we shall examine the electricity which is produced by the contact, or by the action, of metallic and other conducting substances upon each other, under the title of *Galvanism;* though in truth Galvani's discove-

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ries go no further than what relates to certain effects of the contact of animal parts principally with metallic substances.—I shall briefly describe the principal facts which relate to the above-mentioned sort of muscular motion, and shall then proceed to those which relate to the wonderful effects of the mere contact or action of one conducting substance upon another, amongst which the metallic are the most conspicuous.

191. The action of electricity on a frog, recently dead, and skinned, (and indeed on other animals more or less) occasions a tremulous motion of the muscles, and generally an extension of the limbs.

Dr. Galvani used to skin the legs of a frog recently dead, and to leave them attached to a small part of the spine, but separated from the rest of the body.—Any other limb may be prepared in a similar manner; viz. the limb is deprived of its integuments, and the nerve, which belongs to it, is partly laid bare.

If the limbs thus prepared, for instance, the legs of a frog, be situated so that a little electricity may pass through them, be it by the immediate contact of an electrified body, or by the action of electric atmospheres (as when the preparation is placed within a certain distance of an electrical machine, and a spark is taken from the prime conductor); the prepared legs will be instantly affected with a kind of spasmodic contraction, sometimes so strong as to jump a considerable way.

When the electricity is caused to pass through the prepared frog by the immediate contact of the electrified body, a much smaller quantity of it is sufficient to occasion the movements, than when it is made to pass from one conductor to another, at a certain distance from the prepared animal.*

* Probably the 100th part of that electricity which can affect a very delicate electrometer, is sufficient to produce the movement of the prepared animal limb, and even of a whole frog, or mouse, or sparrow, &c.

The movements are much stronger when the electricity is caused to pass through a nerve to the muscle or muscles, than through any other part.

The sensibility of the prepared animal is greatest at first, but it diminishes by degrees till it vanishes entirely. Animals with cold blood, and especially frogs, retain that sensibility for several hours, sometimes even for a day or two. With other animals the sensibility does not last long after death, and sometimes not above a few minutes.

The like movements may be produced in the prepared animal without the aid of any apparent electricity. In an animal recently dead, detach one end of a nerve from the surrounding parts, taking care to cut it not too near its insertion into the muscle; remove the integuments from over the muscles which depend on that nerve; take a piece of metal, as a wire, touch the nerve with one extremity of it, and the muscles with its other extremity; on doing which you will find that the prepared limbs move in the same manner as when some electricity is passed through them. This however is not the most effectual way of forming the communication; yet it will generally succeed, and the experiment will answer whether the preparation be laid upon conductors or upon electrics.

If the communication between the nerve and the muscle be formed by the interposition of nonconductors of electricity, such as glass, sealing-wax, &c. no movements will take place.

When the application of the metal or metals is continued upon the parts, the contractions will cease after a certain time, and on removing the metal, seldom, if ever, any contraction is observed.

The conducting communication between the muscle and the nerve may consist of one or more pieces, and of the same or, much better, of different bodies connected together, as metals, water, a number of persons, and even wood, the floor of a room, &c.* But it must be

* The various bodies, which form this circuit, must be placed

observed, that the less perfect conductors will answer only at first, when the prepared animal is vigorous; but when the power begins to diminish, then the more perfect conductors only will answer, and even these will produce various effects.

The most effectual way of producing those movements in prepared animal parts is by the application of two metals, of which silver and zinc seem upon the whole to be the best, though silver and tin, or copper and zinc, and other combinations, are not much inferior. If part of the nerve proceeding from a prepared limb be wrapped up in a bit of tin-foil, or be only laid upon zinc, and a piece of silver be laid with one end upon the bare muscle, and with the other upon the above-mentioned tin or zinc, the motion of the prepared limb will be very vigorous. The two metals may be placed not in contact with the preparation, but in any other part of the circuit, which may be completed by means of other conductors, as water, &c.

The best preparation for this experiment is made in the following manner:

Separate with a pair of scissors the head and upper extremities of a frog from the rest of the body. Open the integuments and muscles of the abdomen, and remove the entrails, by which means you will lay bare the crural nerves. Then pass one blade of the scissors under the nerve, and cut off the spine with the flesh close to the thighs, by which means the legs will remain attached to the spine by the nerves alone. This done, leave a small bit only of the spine attached to the crural nerves, and cut off all the rest. Thus you will have the lower limbs of the frog adhering to the bit of spine by means of the crural nerves. The legs must be flayed in order to lay bare the muscles; and a bit of tinfoil should be wrapped round the spine. With this preparation the experiment may be performed various ways, but the two which follow are the best.

Hold the preparation by the extremity of one leg, the other leg hanging down, with the armed bundle of nerves and spine laying upon it. In this situation interpose a piece of silver, as a half-crown, between the lower thigh and the nerves, so that it may touch the former with one surface, and the metallic coating of the latter with the other surface, or with its edge; and you will find that the hang-

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in full and perfect contact with each other, which is done by pressing them against each other, or by the interposition of water, &c.

ing leg will vibrate very powerfully, sometimes so far as to strike against the hand of the operator, which holds the other leg.

Otherwise, place two wine-glasses, both full of water, contiguous to each other, but not actually touching. Put the thighs and legs of the preparation in the water of one glass, and laying the nerves over the edges of the two glasses, let the bit of spine with its armour (viz. tin-foil) touch the water of the other glass. Things being thus prepared, if you form the communication between the waters of the two glasses, by means of silver, or put the fingers of one hand into the water of the glass that contains the legs, and holding a piece of silver in the other, you touch the coating of the nerves with it, you will find that the prepared legs move so powerfully as sometimes to jump fairly out of the glass.

192. By the application of armours of different metallic substances, and forming a communication between them, the motions may be excited even in an entire living frog, as also in some other living animals, particularly eels and flounders. The living frog is placed upon a piece of zinc, with a slip of tin-foil pasted upon its back. This done, whenever the communication is formed between that zinc and the tin-foil, especially if silver be used, the spasmodic convulsions are excited, not only in the muscles which touch the metallic substances, but likewise in the neighbouring muscles. This experiment may be performed entirely under water.

The experiment may be performed with a flounder in a similar, easy, and harmless manner. Take a living flounder, wipe it pretty dry, and lay it flat into a pewter plate, or upon a sheet of tin-foil, and place a piece of silver, as a shilling, a crown piece, &c. upon the fish. Then, by means of a piece of metal, complete the communication between the pewter plate or tin-foil and the silver piece; on doing which the animal will give evident tokens of being affected. The fish may afterwards be replaced in water, and preserved for further use.

It seems that such movements may be excited by the contact of metallic substances in all the animals; at least they have succeeded, but in different degrees, in a great variety of animals, from the ox to the fly.

The human body, whilst undergoing certain chirurgical operations, or its amputated limbs, have been convulsed by the application of metals. But the living animal body may be rendered sensible of the action of metallic application in a harmless way, and both the senses of taste and of sight may be affected by it, but in different degrees according to the various constitutions of individuals.

Let a man lay a piece of metal upon his tongue, and a piece of some other metal under the tongue; on forming the communication between those two metals, either by bringing their outer edges in contact, or by the interposition of some other piece of metal, he will perceive a peculiar sensation, a kind of irritation, accompanied with a sort of cool and subacid taste, not exactly like, and yet not much different from that which is produced by artificial electricity. The

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metals which answer best for these experiments, are silver and zinc, or gold and zinc. The sensation seems to be more distinct when the metals are of the usual temperature of the tongue. The silver or gold may be applied to any other part of the mouth, to the nostrils, to the ear, or to other sensible parts of the body, whilst the zinc is applied to the tongue; and on making the communication between the two metals, the taste will be perceived upon the tongue. The effect is rather more remarkable when the zinc touches the tongue in a small part, and the silver in a great portion of its surface, than *vice versa*. Instead of the tongue, the two metals also may be placed in contact with the roof of the mouth, as far back as possible; and on completing the communication, the taste or irritation will be perceived.

Different persons are variously affected by this application of metals; with some the sensation or taste is so slight as to be hardly perceived, whilst with others it is very strong and even disagreeable. Some persons feel merely a pungency, and not properly a taste.

In order to affect the sense of sight by means of metals, let a man in a dark place put a slip of tin-foil upon the bulb of one of his eyes, and let him put a piece of silver, as a spoon or the like, in his mouth. On completing the communication between the spoon and the tin-foil, a faint flash of white light will appear before his eyes. This experiment may be performed in a more convenient manner, by placing a piece of zinc between the upper lip and the gums, as high up as possible, and a silver piece of money upon the tongue; or else by putting a piece of silver high up in one of the nostrils, and a piece of zinc in contact with the upper part of the tongue; for in either case the flash of light will appear whenever the two metals are made to communicate, either by the immediate contact of their edges, or by the interposition of other good conductors.

By continuing the contact of the two metals, the appearance of light is not continued, it being only visible at the moment of making the contact, and sometimes, though rarely, at the instant of separation: it may therefore be repeated at pleasure, by disjoining, and again connecting, the two metals. When the eyes are in state of inflammation, then the appearance of light is much stronger.

193. When the science of electricity was advanced no further than the knowledge of the above-mentioned facts, it was doubtful whether the convulsions of prepared animal limbs, and the sensations which are produced by the application of metallic substances, were owing to some electrical property peculiar to the animal parts, which might perhaps be conducted through the metals from one part to the other; or to a small quan-

tity of electricity, which might be supplied by the metals themselves. The latter supposition however was soon verified by the result of various experiments, which prove in the most convincing manner that electricity is produced by the mere contact, not only of metallic substances, but likewise of other bodies.

The electricity thus produced by the mere contact of two bodies is so very small as not to be perceived without great care, and without using some of those artifices for discovering small quantities of electricity, which have been mentioned above. But the late discoveries of the ingenious Mr. Volta have shown a method of increasing that electricity to a most extraordinary degree; by which means the subject of electricity has received a remarkable advancement, and has opened a most promising field of wonders, wherein numerous and able labourers are daily making useful and admirable discoveries.

194. We shall now proceed to state those facts in as compendious a manner as the nature of the subject will admit of.

Previous to the above-related discoveries of Galvani and others, a variety of facts, frequently asserted, imperfectly known, and often disbelieved, indicated a peculiar action arising from a combination of different metallic bodies in certain cases.

It had been long asserted, that when porter (and some other liquors also) is drunk out of a pewter pot, it has a taste different from what it has when drunk out of glass or earthen-ware.

It has been observed, that pure mercury retains its metallic splendour during a long time; but its amalgam with any other metal is soon tarnished or oxidated.

The Etruscan inscriptions, engraved upon pure lead, are preserved to this day; whereas some medals of lead and tin, of no great antiquity, are much corroded.—Works of metal, whose parts are soldered together by the interposition of other metals, soon tarnish about the places where the different metals are joined.

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When the copper sheathing of ships is fastened on by means of iron nails, those nails, but particularly the copper, are readily corroded about the place of contact.*

It had been observed, that a piece of zinc might be kept in water for a considerable time, without hardly oxidating at all; but that the oxidation would soon take place if a piece of silver happened to touch the zinc, whilst standing in water.

Since Galvani's discoveries, the action arising from the combination of three conductors has been examined with great care, and with considerable success, especially by Volta, who lately discovered that the slight effect of such a combination may be increased to a prodigious degree by repeating the combination; for instance, if a combination of silver, zinc, and water, produce a certain effect, a second combination (viz. another piece of silver, another piece of zinc, and another quantity of water) added to the first, will increase the effect; the addition of a third combination will increase the effect still more, and so on.

195. Previous to the description of the construction, and of the very remarkable effects of those repeated combinations, which are now generally called *Galvanic batteries* (though in justice they must be called *Volta's batteries*, or *Voltaic batteries*) it will be necessary to state the principal laws, which have been pretty well ascertained with respect to the simple combinations.

I. The conductors of electricity, which, strictly speaking, do almost all differ from each other in conducting power, are nevertheless divided into two principal classes. Those of the first class, otherwise called *dry* and *perfect* conductors, are the metallic substances and charcoal. Those of the second class, or the *imperfect conductors*, are water, and other oxidating fluids, as also the substances which contain those fluids. The substances

* See Fabroni's Paper on the Action of different Metals upon each other, in the 40th number of Nicholson's Journal.

of the second class differ in conducting power much more than those of the first.

II. The simplest combinations capable of producing Galvanic effects, (viz. to convulse the prepared limbs of a frog, or of exciting the taste upon the tongue, &c.) must consist of three different conductors; for, two conductors only will not produce any sensible effect. If the three conductors be all of the first class, or all of the second, then the effect is seldom sensible. In this case such conductors of the second class as differ more from each other, are more likely to produce a sensible effect than those of the first class.* But a proper active simple combination must consist of three different bodies; viz. of one conductor of one class, and two different conductors of the other class.

When two of the three bodies are of the first class, and one is of the second, the combination is said to be of the *first order;* otherwise it is said to be of the *second order*.

In a single active Galvanic combination, or, as it is commonly called, in a *simple Galvanic circle*, the two bodies of one class must touch each other in one or more points, at the same time that they are connected together at other points by the body of the other class. Thus, when a prepared frog is convulsed by the contact of the same piece of metal in two different places; then the fluids of those parts, which must be somewhat different from each other, are the two conductors of the second class, and the metal is in the third body, or the conductor of the first class. If two metals be used, then the fluids of the prepared animal, differing but little

* Volta adduces as an instance of an active Galvanic combination, consisting of three conductors of the second class only, an experiment of Dr. Valli, in which the three bodies concerned were, 1st, The leg of a frog, and particularly the hard tendinous part of the *musculus gastrocnemius;* 2d, The rump, or the muscles of the back, or the ischiatic nerves, to which the said tendinous parts are applied; and 3d, The blood or the viscous saponaceous or saline fluid, applied to the point of contact.

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from each other, may be considered as one body of the second class. Thus also, when a person drinks out of a pewter mug, the saliva or moisture of his under lip is one fluid or one conductor of the second class, the liquor in the mug is the other, and the metal is the third body, or conductor, of the first class.

III. It seems to be indispensably requisite, that in a simple Galvanic circle, the conductor or conductors of one class should have some chemical action upon the other conductor or conductors; without which circumstance the combination of three bodies will have either no Galvanic action at all, or a very slight one. Further, the Galvanic action seems to be proportionate to the degree of chemical agency; which seems to show that such chemical action is the primary cause of the electric phenomena.

The most active Galvanic circles of the first order, are when two solids of different degrees of oxidability are combined with a fluid capable of oxidating at least one of the solids. Thus gold, silver, and water, do not form an active Galvanic circle; but the circle will become active if a little nitric acid, or any fluid decomposeable by silver, be mixed with the water.

A combination of zinc, silver, and water, forms an active Galvanic circle, and the water is found to oxidate the zinc, provided the water holds some atmospherical air, as it commonly does, and especially if it contain oxygen air. But zinc, silver, and water, containing a little nitric acid, form a more powerful Galvanic circle, the fluid being capable of acting both upon the zinc and upon the silver.

The most powerful Galvanic combinations of the second order, are when two conductors of the second class have different chemical actions on the conductors of the first class, at the same time that they have an action upon each other. Thus copper, or silver, or lead, with a solution of an alkaline sulphuret, and diluted nitrous acid, form a very active Galvanic circle.

The following lists contain a useful arrangement of the best combinations, disposed in the order of their powers, and commencing with the most powerful.*

* This arrangement has been formed principally by Mr. Davy, professor of chemistry at the Royal Institution.

Galvanic circles of the First Order, viz. which consist of two Conductors of the First Class, and one of the Second.

Zinc with gold, or charcoal, or silver, or copper, or tin, or iron, or mercury; and water containing a small quantity of any of the mineral acids.*

Iron, with gold, or charcoal, or silver, or copper, or tin, and a weak solution of any of the mineral acids, as above.

Tin, with gold, or silver, or charcoal, and a weak solution of any of the mineral acids, as above.

Lead, with gold, or silver, and a weak acid solution, as above.

Any of the above metallic combinations, and common water, viz. water containing atmospherical air, or especially water containing oxygen air.

Copper, with gold, or silver, and a solution of nitrate of silver and mercury; or the nitric acid; or the acetous acid.

Silver, with gold, and the nitric acid.

Galvanic Circles of the Second Order, viz. which consist of one Conductor of the First Class, and two of the Second.

Charcoal, or Copper, or Silver, or Lead, or Tin, or Iron, or Zinc,	with water, or with a solution of any hydrogenated alkaline sulphurets, capable of acting on the first three metals only;	and a solution of nitrous acid, or oxygenated muriatic acid, &c. capable of acting upon all the metals.

The action of a simple Galvanic circle seems to be in some measure dependent upon the quantity of surface of contact between the acting bodies. A higher temperature within certain limits, renders the activity of the circle greater than a lower temperature.

The activity of a Galvanic circle is not altered by the interposition of such conductors as have no action upon the adjoining conductors of the circle. Thus, if a circle consist of zinc, gold, and water; and if you interpose a piece of iron, or of silver, or both, between the zinc and the gold, the activity of the circle will not be altered thereby. Hence it appears that the action of a Galvanic circle may be conveyed through extraneous conductors to a considerable distance; but it must be observed, that the activity is weakened by the great length of the conductors, especially if they be of an imperfect nature.

* Van Marum found a solution of sal ammoniac, viz. of the muriate of ammonia, to act best.

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IV. When the three bodies which form a Galvanic circle of the first order are laid one upon the other, but the lower and the upper one do not touch each other; then these two extremes are in opposite electric states, viz. the extremity which is next to that metallic surface that touches the body of the second class, is positive, and the opposite extremity is negative. Thus let copper, zinc, and moistened leather, be laid one upon the other, and the upper end, viz. the wetted leather, will be found possessed of positive electricity, whilst the lower end, or the copper, will be found negative.*

V. The Galvanic effects may be increased to almost any degree, by connecting several of the above-mentioned active combinations, or by a repetition of the same simple Galvanic combination (the most active simple combinations forming the most powerful batteries, and *vice versa*) provided the simple combinations are disposed so as not to counteract each other.†

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* From experiments and from deduction (which may be made from the effects of batteries) we conclude, that every active Galvanic combination has a positive and a negative side. Hence it is supposed, that when the circle is completed, a circulation of electric fluid takes place through it.

† This restriction will be easily understood by considering that every simple, but interrupted, Galvanic combination, has a positive and a negative end; or that in every complete Galvanic circle the electric fluid circulates in one way only. Thus, if the two simple combinations (each consisting of silver, zinc, and wet cloth, as is indicated by the letters *s*, *z*, *w*) be disposed, as in fig. 85., this arrangement will not have any Galvanic power, because the actions of the two simple combinations, or the two currents of electricity, are opposed to each other; the two positive, and the two negative ends being respectively at *p* and *n*.

What is here said of the arrangement of two simple combinations, must also be understood of the connexion of any number of the same; viz. they must not counteract each other; or, if a certain number of them counteract each other, then the remaining only form the active part of the battery. For instance, if a battery consist of 40 simple combinations, and if 12 of them are placed in a direction contrary to the others; then those 12 will counteract 12 others, and of course the whole battery will have no more power than if it consisted of 16 simple combinations properly disposed.

If

Those batteries are said to be of the first or of the second order, according as the simple combinations, of which they consist, are of the first or of the second order. Thus, if a piece of zinc be laid upon a piece of copper, and a piece of moistened card be laid upon the zinc; then a similar arrangement of three other such pieces be laid upon them, and a third arrangement be laid upon this, &c. all in the same order; the whole will form a battery of the first order. But if the arrangement be made by connecting a piece of copper with a piece of cloth moistened with water; the latter with a piece of cloth moistened with a solution of sulphuret of potash, and this again with another piece of copper, &c. the whole will form a battery of the second order.

196. Let us now proceed to describe the practical construction, and the effects of Galvanic combinations, especially of the compound arrangements or batteries.

The simplicity of single Galvanic circles is so great, that nothing more needs be said with respect to their construction.

Voltaic batteries have been constructed of various shapes, and they may be endlessly diversified.

The battery represented by fig. 86., consists of several glasses, or china cups full of water, or of water containing salt, &c. and two plates unconnected with each other, viz. a plate of zinc and a plate of silver, are plunged in the fluid of each cup, excepting the first and last cups; but each of those plates must have a sort of tail or prolongation, by which they are so connected that the silver plate of one cup communicates with the zinc plate of the next, and so on; those prolongations being soldered at *a*, *a*, *a*, &c.

The battery, fig. 87., consists of pieces of silver, about as big as half crowns, pieces of zinc, about equal to those of silver, and pieces of card, or cloth, or leather, or other bibulous substance, a little smaller in diameter than the metallic pieces, and soaked in water or in other proper fluid.

If two batteries be connected in an inverted order, then by a proper management their respective powers may be compared, as may be readily deduced from the observations just now made.

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Those pieces are disposed in the order of silver, zinc, and wet cloth, &c. The pieces of card, or cloth, &c. must be well soaked in the fluid; but before they are applied, they should be gently squeezed, in order that the superfluous fluid may not run down the outside of the pile, or insinuate itself between the contiguous pieces of silver and zinc. Those pieces, especially if soaked in plain water, lose their moisture pretty soon, so that they can hardly serve longer than for a day or two; after which time the pile must be decomposed, the metallic pieces cleaned, those of cloth or card soaked again, and the whole arranged as before.

The three rods R, R, R, are of glass or of baked wood, and the piece of wood, O, slides freely up or down the rods. This serves to prevent the falling of the pieces.

When such a battery is to be very powerful, viz. is to consist of numerous pieces, the best way is to form two or three or more piles, and to join them by pieces of metal, as in fig. 88., where two piles are joined together, so that *a* is the negative, and *b* the positive extremity of the whole arrangement.

Batteries may also be formed as follows: A strong oblong vessel, about three inches deep, and about as much broad, is made of baked wood. In the sides of this vessel grooves are made opposite to each other, and about one eighth of an inch in depth. In each pair of opposite grooves a double metallic plate (suppose a plate of zinc and a plate of silver soldered together at their edges) is cemented; by which means the wooden vessel is divided into several partitions, or cells, about half an inch broad. The cementation of the metallic pieces into the sides and the bottom of the wooden vessel, must be so accurate as not to permit the passage of any fluid from one cell into the next. The cement proper for this purpose has been described in the 2d note of chap. V.

Those cells are afterwards filled almost to the top with water, or any other fluid, according to the table of

Galvanic circles of the first order given in the preceding article; and thus the whole will form a voltaic battery, consisting of various repetitions of silver, zinc, and fluid. Two or more of such batteries may be joined, as has been said of the preceding battery.

The action of all those batteries is greatest when they are first completed or filled with the fluid; and it declines in proportion as the metal is oxidated, or the fluid loses its power. Hence, after a certain time, not only the fluid must be changed, but the metallic pieces must be cleaned by removing the oxidated surface, &c.

197. The mode of applying single Galvanic circles and their principal effects, have already been described; yet, for the sake of assisting the memory, it will be useful to collect those effects under the four following heads.

I. The action of a single Galvanic circle affects the organs of living animals, or of animals recently dead, especially when one end of the combination is connected with a nerve, and the other end is connected with a muscle of the same limb.

II. That action may be transmitted through good conductors of electricity, but not through electrics, or through less perfect conductors.

III. It affects the electrometer by the intermediation of other instruments.

IV. That action increases, or otherwise modifies, the chemical agency of the bodies concerned, upon each other.

The limbs of animals, especially of frogs recently dead, are the most sensible instruments of Galvanic powers; and, in fact, the simplest Galvanic circles will affect them, when they will not produce any other decisive electrical effect.

The various powers of different simple circles may be ascertained by applying them to such animal preparations as have their vitality, or irritability, more or less exhausted. Thus Mr. Volta, in his letter to Gren, says, "If you take a frog, the head of which has been cut off, and which has been deprived of all life by thrusting a needle into the spinal marrow, and immerse it without skinning, taking out the bowels, or any other preparation, into two glasses of water; the rump into one, and the legs into the other, as usual; it

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will be strongly agitated and violently convulsed, when you connect the water in both glasses by a bow formed of two very different metals, such as silver and lead, or, what is better, silver and zinc; but this will by no means be the case when the two metals are less different in regard to their powers, such as gold and silver, silver and copper, copper and iron, tin and lead. But what is more, the effect will be fully produced on this so little prepared frog, when you immerse in one of the two glasses the end of a bow merely of tin or zinc, and into the other glass the other end of this bow which has been rubbed over with a little alkali. You may perform the experiment still better with an iron bow, one end of which has been covered with a drop or thin coating of nitrous acid; and beyond all expectation, when you take a silver bow, having a little sulphuret of potash adhering to its extremity."

When a single powerful Galvanic combination of the second order is applied with one end to the tongue, and with the other fluid end to some other sensible part of the body, an acid taste is perceived on the tongue, which taste, by continuing the contact, becomes less distinct, and is even changed into an alkaline taste.

" If a tin bason be filled with soap-suds, lime water, or a strong ley, which is still better; and if you then lay hold of the bason with both your hands, having first moistened them with pure water, and apply the tip of your tongue to the fluid in the bason, you will immediately be sensible of an acid taste upon your tongue, which is in contact with the alkaline liquor. This taste is very perceptible, and, for the moment, pretty strong; but it is changed afterwards into a different one, less acid, but more saline and pungent, until at last it becomes alkaline and sharp, in proportion as the fluid acts more upon the tongue."*

Mr. Davy observes, that " if zinc and silver be made to form a circle with distilled water, holding in solution air, for many weeks, a considerable oxidation of the zinc is perceived, without the perceptible evolution of gas; and the water, at its point of contact with the silver, becomes possessed of the power of tinging green, red cabbage juice, and of rendering turbid, solution of muriate of magnesia."

The chemical action of bodies upon each other is increased by the Galvanic arrangement, so much, that some of them are thereby enabled to act upon bodies which otherwise they would have no action upon. Fig. 89. represents a glass tube about four inches long. Two corks are thrust into its apertures A and B. An oblong piece of zinc, CD, is fixed into one of the corks, and is made to project within and without the tube. EFG is a silver wire, which, being fixed into the other cork, projects with the extremity E within the tube; and its other extremity is bent so as to come near the projecting part of the zinc C.

* Volta's Letter to Gren.

Remove one of those corks, and fill the tube with water, in which you must mix a drop or two of muriatic acid; then replace the cork, and you will find that the zinc is acted upon by the diluted acid; is oxidated by it, and bubbles of gas are evolved from it; but the silver wire E remains untouched, and no gas whatever is evolved from it. Now, if you bend the silver wire FG, so that its end G may touch the zinc at C, then the Galvanic circle of silver, zinc, and diluted acid is completed, in consequence of which the diluted acid is enabled to act stronger upon the zinc D, which is manifested by the more copious evolution of gas, and is, besides, enabled to act upon the silver wire, for now you will observe the evolution of gas from the silver E also.—Break the contact between G and C, and the silver E will cease to yield gas.—Form it again, and gas will again proceed from the silver.

Instead of silver, zinc, and diluted muriatic acid, you may in the same manner use gold, tin, and diluted nitric acid; and by completing the circle, the acid will be enabled to act upon the gold.

It has been observed, that whenever an oxidating influence is exerted at one of the places of contact of the perfect and imperfect conductors, a deoxidating action appears to be produced at the other place. Thus when iron, which oxidates rapidly when forming a circle with silver and common water, is arranged with zinc and common water, it remains perfectly unaltered, whilst the zinc is rapidly acted upon.*

Such are the facts which have as yet been discovered with respect to the power of single Galvanic circles. They form a remarkable addition to the science of electricity, and open a vast field of speculation and experimental investigation; yet we are unable to form a theory sufficient to account for the original cause, or for the action of that very remarkable power.

198. If the effects of single circles are very remarkable, the collected power of several single circles, or of the Voltaic battery, cannot fail of surprising the least reflecting mind.

The Voltaic battery not only convulses the prepared limbs of a frog, or produces the appearance of a flash of light before the human eye; but it shows all the phenomena of electricity in a very considerable degree. It gives the shock; it affects the electrometer; shows a luminous spark, accompanied with an audible report; it burns metallic, and other combustible bodies; and continues in action for a very long time, viz. until the

* Journals of the Royal Institution, No. 4.

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chemical action between the component parts of the battery is quite exhausted.—The following paragraphs contain a more particular, yet concise, enumeration of those wonderful effects.

When Volta's battery of the first order (the action of those of the second order being weaker and much more transient) consists of 20 repetitions of simple combinations, if you touch with one hand one extremity, and apply your other hand to the other extremity of the battery, you will feel a very slight shock, like that which is communicated by a Leyden phial weakly charged, and it will be hardly felt beyond the fingers, or at most the wrists. This shock is felt as often as you renew the contact. If you continue the hands in contact with the two extremities, you will perceive a slight but continuate irritation: and, when the hand or other part of the body, which touches the extremity of the battery, is excoriated or wounded, this sensation is disagreeable and rather painful.

The dry skin of the human body is seldom capable of conducting this shock; therefore the touching fingers should be well moistened with water. It will be better to immerse a wire that proceeds from one extremity of the battery, in a bason of water, wherein you may plunge one of your hands; then grasping with your other hand well moistened, a large piece of metal, for instance, a large silver spoon, touch the other end of the battery with it, and the shock will be felt more distinctly. By this means the shock has been felt when the battery consisted of less than 20 repetitions.

Instead of one person, several persons may join hands, (which must be well moistened with water) and on completing the circuit, they will all feel the shock at the same instant.

The shock from a battery consisting of 50 or 60 repetitions of the most active combinations of the first order may be felt as far as the elbows; and the combined force of 5 or 6 such batteries will give a shock perhaps much stronger than most men would be willing

to receive. The prepared limbs of a frog or other animal are violently convulsed, but soon exhausted of their irritability, by the action of a Voltaic battery.

This shock is similar to that of a large common electrical battery weakly charged, and not to that of a small Leyden phial fully charged. The difference consists in this, viz. that the latter contains a small quantity of electric fluid highly condensed; hence its discharge will force its way through perhaps an inch of air; whereas the former contains a vast quantity of electricity, but little condensed; hence its spark, viz. its course through the air, is so very short, that the fingers must be brought almost into perfect contact in order to receive the shock; and such is the case with the Voltaic battery; for the shock from a very powerful battery of this sort will hardly ever force its way through the air, when the extremities of the circle of communication are more than a fortieth of an inch distant, even when those extremities consist of perfect conductors. In this case a small but very vivid spark is seen at that extremity, accompanied with an audible but not strong report. There is no perceptible difference of appearance between the spark of the positive and that of the negative end of the battery.

If a wire proceeding from one extremity of a pretty strong Voltaic battery be made to communicate with the inside coating, and a wire, which proceeds from the other extremity of the Voltaic battery, be made to communicate with the outside coating of a common large jar or electrical battery; the latter will thereby become *weakly*, but almost *instantaneously*, charged, in the same manner as if it had been charged by a few turns of a common electrical machine; and with that charge you may either give the shock, or affect an electrometer, &c.

In short, every thing conspires to prove that a Voltaic battery produces a vast quantity of electric fluid, but which is little condensed; and indeed it would be impossible to suppose, that the electric fluid could proceed in a very condensed state from an arrangement of bodies, which, whether more or less, are, however, all good conductors of electricity; for if the fluid were much condensed at one extremity of the Voltaic battery, and much rarefied at the other extremity, the compensation would soon be made through the pile itself. Indeed it is difficult to comprehend how this compensation does not take place in all cases.

The electric fluid may probable be a necessary ingredient in the composition of bodies; and perhaps the chemical action of one body upon another disengages from the latter the electric fluid, as it disengages the caloric in several cases: but the question is, why the electric fluid, which is extricated from the bodies of a Voltaic

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battery, is forced to move one way; and why is the other extremity of the battery in a negative state of electricity?

Those doubts may perhaps be cleared by future discoveries.

The spark, or the discharge of a Voltaic battery, when sent through thin inflammable bodies that are in contact with common or oxygen air, sets them on fire, and consumes them with wonderful activity. It fires gunpowder, hydrogen gas, phosphorus, and other combustibles; it renders red-hot, fuses, and consumes very slender metallic wires and metallic leaves. The mode of applying the power of the battery for such purposes, is as follows: Let a wire communicate with the last plate of one side of the battery; and let another wire communicate with the last plate of the other side; if the two other extremities of those wires* be brought sufficiently near to each other, the spark will be seen between them. It is between those extremities that the combustible substances, or metallic leaf, &c. is to be placed, in order to be fired or consumed.†

Under the exhausted receiver of the air-pump, the Voltaic battery acts less powerfully than in the open air; but in oxygen air it acts with increased power.

The flash of light which appears before the eye of the experimenter, when the eye itself, or some other part not very remote from it, is put in the circuit of a Galvanic combination, does not appear much greater when a battery is employed, than when two plates are applied in the manner which has been already mentioned; but when the battery is used, the sensation of a flash may be produced in various ways. If one hand or both be placed in perfect contact with one extremity of the battery, and almost any part of the face be brought into

* These wires are made to pass through, and are fastened into glass tubes, to the middlemost part of which the operator may apply his fingers, so as to move the wires without receiving a shock.

† A battery consisting of 200 pairs of metallic plates (viz. copper and zinc, each 5 inches square) melted 23 inches of very fine iron wire. A platina wire about $\frac{1}{175}$ inch in diameter, was melted into a globule.

contact with the other extremity, the flash will appear very distinctly; the experimenter being in the dark, or keeping his eyes shut. This flash appears very strong, when a wire which proceeds from one extremity of the battery is held between the teeth, and rests upon the tongue, whilst the other wire is held in the hand. In this case the lips and the tongue are convulsed, the flash appears, and a very pungent taste is perceived.

199. The most extraordinary phenomena of a Voltaic battery are the chemical effects, and the modifications which are produced by it upon the bodies concerned, or upon such as are placed in the circuit.

AB, fig. 90, exhibits a glass tube full of distilled water, and having a cork at each extremity. EF is a brass or copper wire, which proceeds from one extremity of a Voltaic battery, and. passing through the cork A, projects within the tube. HG is a similar wire, which proceeds from the other extremity of the battery, and comes with its extremity G within the distance of about an inch or two from the wire F.

In this situation of things, you will find that bubbles of gas proceed in a constant stream from the surface G of the wire which proceeds from the negative end of the battery; these bubbles of gas, ascending to the upper part of the tube, accumulate by degrees. This gas is the hydrogen, and may be inflamed. At the same time the other wire F deposits a stream of oxide in the form of a steam or cloud, which gradually accumulates in a greenish form in the water, or on the sides of the tube, and is a perfect oxide of the brass. The wire F is readily discoloured and corroded. If you interrupt the circuit, the production of gas and of oxide ceases immediately.—Complete the circuit, and the production of gas reappears, &c.

This production of gas may be observed even where the battery consists of not more than six or eight repetitions of silver, zinc, and water. In short, if the power of the battery be sufficient to oxidate one of the wires of communication, the other wire will afford hydrogen gas; both extremities of the wires being in water.*

* In this experiment it seems that the hydrogen is separated from the water, and is converted into a gaseous state by the wire connected with the negative extremity of the battery; whilst the oxygen unites with and oxidates the wire connected with the positive end of the battery If you connect the positive end of the battery with the lower wire of the tube, and the negative with the upper; then the hydrogen proceeds from the upper wire, and the lower wire is oxidated.

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In the above described apparatus, a little hole must be made in the lower cork B, for the purpose of giving exit to the water in proportion as the gas is formed.

"In all batteries of the first order, when the connexion is completed, changes take place which denote the evolution of influences capable of producing from *common* water, oxygen and hydrogen, acid and alkali, in different parts of the series.

"Thus in the battery with series of zinc plates, silver wires, and common water, oxide of zinc is formed on all the plates of zinc, whilst hydrogen is produced from the silver wires; and if the water in contact with them be tinged with red cabbage juice, it becomes green.

"And in the battery with silver, gold, and weak nitric acid, the silver is dissolved, whilst the acid becomes green, and slowly evolves gas at its points of contact with the gold.

"From some experiments it would appear probable that the quantities of hydrogen, produced in series, are small, and the quantities of alkali great, in proportion as the surfaces of contact of the least oxidable metals with the water are more extended.

"All the oxygenated solutions of bodies possessing less affinity for oxygen than nascent hydrogen, are decomposed when exposed to the action of the metal occupying the place of the least oxidable part of the series in the compound circle.

"Thus, sulphur may be produced from sulphuric acid; and copper and other metals precipitated in the metallic form from their solvents.*

If two wires of gold or platina be used, which are not oxidable; then the stream of gas issues from each, the water is diminished, and the collected gas is found to be a mixture of hydrogen and oxygen. It explodes violently.

Those two different elastic fluids may be obtained separate from each other by the following means Let the extremities of the two wires, which proceed from the battery, be immersed in water, at the distance of about an inch from each other, and place over each of them a small glass vessel inverted and full of water. However, Dr. Priestley, who denies the convertibility of water into hydrogen and oxygen air, thinks that the elastic fluid in these experiments originates from the air which is contained in the water; "since," says he, "if by means of oil upon the water, or a vacuum, access to the atmosphere be cut off, the whole production of gas ceases." Nor is any air produced when the water has been exhausted of it.

* "It is well known that hydrogen gas, in its nascent state, reduces the oxides of metals. Accordingly, when the tube, fig. 90, is filled with a solution of acetite of lead in distilled water, and a communication is made with the battery as above described, no gas is perceived to issue from the wire which proceeds from the negative

"But little knowledge has yet been obtained concerning the chemical changes taking place in the batteries of the second order. But from several experiments it would appear that they are materially different in the laws of their production from those taking place in the first order.

"Thus, when single metallic wires with water are placed as series in powerful batteries of the second order, the influence producing oxygen seems to be transmitted by the point, in the place of that part of the plate, which was apparently incapable of undergoing oxidation; whilst the hydrogen is evolved from that point, where the oxidating part of the primary series appeared to exist.

"The agency of the Galvanic influence, which occasions chemical changes, and communicates electrical charges, is probably, in some measure, distinct from that agency which produces sparks, and the combustion of bodies.

"The one appears (all other circumstances being similar) to have little relation to surface in compound circles, but to be great, in some unknown proportion, as the number of series are numerous. The intensity of the other seems to be as much connected with the extension of the surfaces of the series, as with their number.

"Thus, though eight series composed of plates of zinc and copper, about 10 inches square, and of cloths of the same size, moistened in diluted muriatic acid, give sparks so vivid as to burn iron wire; yet the shocks they produce are hardly sensible, and the chemical changes indistinct; whilst 24 series of similar plates and cloths, about two inches square, which occasion shocks and chemical agencies more than three times as intense, produce no light whatever.

"A measure of the intensity of the power in Galvanic batteries, producing chemical changes, may be derived from the quantity of gas it is capable of evolving from water in a given time."*

200. The preceding facts can hardly leave any doubt with respect to the identity of the Galvanic power, and the electricity which is produced by means of a common electrical machine, or that is brought down from the clouds; but, what is still more remarkable, it reconciles to the same principle the animal electricity, viz. the power of the torpedo, gymnotus electricus, &c. since all the phenomena of the animal electricity agree with those of the Voltaic battery.†

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end of the battery; but in a few minutes, beautiful metallic needles are perceived on the extremity of this wire; these soon increase, and assume the form of a fern, or other vegetable. The lead thus separated is in its perfect metallic state, and very brilliant.

* Journals of the British Royal Institution.

† The most striking circumstance is that the electric organ of

Though the Voltaic battery exhibits all the leading properties of common electricity, such as the attraction, the spark, &c. yet in some effects, viz. the decomposition of water, oxygenation of metals, &c the former seemed to differ considerably from the latter; but those apparent differences have been sufficiently reconciled by some very ingenious experiments and observations of Dr. W. H. Wollaston.†

With respect to the decomposition of water, which was thought to require very powerful electrical machines, he justly suspected, that by reducing the surface of communication, the decomposition of water might be affected with less powerful means; and this was verified by actual experiments. "Having," he says, "procured a small wire of fine gold, and given it as fine a point as I could, I inserted it into a capillary glass tube; and after heating the tube so as to make it adhere to the point, and cover it in every part, I gradually ground it down, till, with a pocket lens, I could discern that the point of the gold was exposed.

"The success of this method exceeding my expectations, I coated several wires in the same manner, and found, that when sparks from the conductors were made to pass through water, by means of a point so guarded, a spark passing to the distance of $\frac{1}{8}$ of an inch would decompose water, when the point exposed did not exceed $\frac{1}{700}$ of an inch in diameter. With another point which I estimated at $\frac{1}{1500}$ of an inch, a succession of sparks $\frac{1}{20}$ of an inch in length, afforded a current of small bubbles of air.

"I have since found, that the same apparatus will decompose water, with a wire $\frac{1}{30}$ of an inch diameter, coated in the manner before described, if the spark from the prime conductor passes to the distance of $\frac{1}{30}$ inch of air."

He also found, that with a gold point similar to, but much smaller than any of the above-mentioned, and similarly situated in water, the mere current of electricity, without any sparks, would occasion a stream of very small bubbles to rise from the extremity of the gold.

Dr. Wollaston likewise remarks another strong point of analogy between the electricity of the Voltaic battery and that of a common electrical machine; viz. that they both seem to depend upon oxidation. In fact, a common electrical machine will act more or less powerfully, according as the amalgam which is applied to its rubber consists of metals that are more or less oxidable.

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any of the above-mentioned fishes seems to be constructed exactly like a Voltaic battery; for it consists of little laminæ or pellicles arranged in columns, and separated by moisture. It seems, in short, to be a Voltaic battery, consisting of conductors of the second order only; but undoubtedly of different conducting powers.

† See his valuable Paper in the Phil. Trans. for 1801, Article XXII.

SECTION IV.

OF MAGNETISM.

CHAPTER I.

Of the Magnet in general.

201. A HARD mineral body, of a dark gray, or dark brown, and sometimes almost black colour, has been called a *natural magnet*, or *loadstone*. This mineral, which is an iron ore, has, from time immemorial, justly attracted the attention of mankind, on account of the very remarkable, and very useful properties, of which it is found naturally possessed, and which are thence denominated *magnetic properties*.*

202. The magnetic properties may also be communicated to other ferruginous bodies by proper methods; so that those bodies will afterwards act exactly like natural magnets; hence the latter are called *artificial magnets*. But the magnetic properties do not seem to have any decided agency upon any other substance, besides iron;† therefore the magnets, whether natural or artificial, and the bodies, upon which they act, are either iron in its pure state, or such compound bodies as contain iron. At least the exceptions are rather equivocal.

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* The word magnet is, by some ancient writers, derived from the name of a shepherd, by whom they suppose the magnet to have been first discovered on Mount Ida. It was in ancient times more commonly called *siderites*, from its property of attracting iron, which metal is called σίδηρος. in Greek; or *lapis heracleus*, by Pythagoras, Aristotle, Euripides, and others, from Heraclea, a city of Magnesia, in ancient Lydia, where it was supposed to have been first found. It has also in later times been called *lapis nauticus*, from its use in navigation.

† The few and trifling exceptions to this general law will be noticed in the sequel.

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203. A magnet, whether natural or artificial, is always possessed of the following characteristic properties, which are inseparable from its nature; so that a body cannot be called a magnet, unless it be possessed of all those properties at the same time; neither was there a magnet ever produced which had one only or a few of those properties:†

1. A magnet attracts iron and other ferruginous bodies.

2. When a magnet is placed so as to be at liberty to move itself with sufficient freedom, it turns one, and constantly the same, part of its surface towards the north pole of the earth, or towards a point not much distant from it; and of course it turns the opposite part of its surface towards the south pole of the earth, or towards a point not much distant from it. Those parts on the surface of the magnet are therefore called its *poles;* the former being denominated its *north pole*, and the latter its *south pole*. This property itself is called *the magnet's directive power*, or *the magnetic polarity;* and when a magnetic body places itself in that direction, it is said to *traverse*. A plane perpendicular to the horizon, and passing through the poles of a magnet when standing in their natural direction, is called the *magnetic meridian*, and the angle which the magnetic meridian makes with the meridian of the place where the magnet stands, is called the *declination of the magnet*, or more commonly *of the magnetic needle* at that place; because the artificial magnets, mostly used for observing this property, are generally made of a slender shape; and sometimes real sewing needles, rendered magnetic, are used for this purpose.

3. When two magnets are placed so that the north

† In the first volume of the Philosophical Magazine, page 426, it is said that the serpentine of Humboldt has some of the magnetic properties only; but the account is imperfect, and, in all probability, incorrect.

pole of one of them is opposite to the south pole of the other, then they attract each other; but if the south pole of one magnet be placed opposite to the south pole of the other, or if the north pole of the one be brought near the north pole of the other; in either case a repulsion takes place. In short, magnetic poles of the same name repel each other; but those of different names attract each other.

4. When a magnet is situated so as to be at liberty to move itself with sufficient freedom, it generally inclines one of its poles towards the horizon, and of course it elevates the other pole above it. This is called *the inclination*, or *dipping of the magnet*, or *of the magnetic needle*.

5. Any magnet may, by proper methods, be made to impart those properties to iron, or to steel, or, in short, to most ferruginous bodies.

The particular laws which have been ascertained with respect to those properties, their uses, and the instruments necessary for those purposes, will be described in the following chapters.

CHAPTER II.

Of Magnetic Attraction, and Repulsion.

204. A PIECE of iron or steel, or other ferruginous substance, sufficiently small, being brought within a certain distance of one of the poles of a magnet, (be it artificial or natural) is attracted by it, so as to adhere to the magnet, and not suffer to be separated without an evident effort.—That this attraction is mutual; viz. the iron attracts the magnet as much as the magnet attracts the iron, has been shown in vol. I. p. 17.

The force or degree of magnetic attraction varies according to different circumstances; viz. a magnet at-

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tracts a piece of soft and clean iron more forcibly than any other ferruginous body of the like shape and weight, especially such as are of a harder nature. Thus hard steel or hard iron ores are attracted less forcibly than soft steel, and the latter less forcibly than iron. Oxigenated iron is attracted less forcibly in proportion as it is combined with more oxygen.

If the piece of iron be presented successively to the various parts of the surface of a magnet, it will be found that the attraction is strongest at the poles of the magnet; that it diminishes in proportion as the part of the surface is more distant from the poles; and that it is hardly perceivable at those parts which are equidistant from the poles of the magnet.

The attraction is strongest near the surface of the magnet, and diminishes as the distance increases; viz. if a piece of iron be placed in contact with one of the poles of a magnet sufficiently strong, they will adhere to each other, and a certain degree of force is required to separate them; but if the same piece of iron be kept at a certain distance from the same pole of the magnet, there will also be perceived an endeavour to attract it; but the force necessary to prevent that attraction, will be found much less than that which, in the preceding case, was found necessary to separate them; and by increasing the distance the attractive force will be found to diminish. Now it is very remarkable, that the law of this diminution of the attractive force has not yet been ascertained, notwithstanding a vast number of experiments which have been made expressly for the purpose. Some philosophers have found it to decrease in proportion to the squares of the distances, others in proportion to the cubes of the distances, and others again have found it to decrease according to one ratio within a certain distance, and according to another ratio beyond that distance. This difference of results arises from the various powers and shapes both of the magnets and of the iron; for as the attraction of the whole arises from the attraction of the parts, it naturally follows that if you gradually remove a piece of iron from the magnet, the distances between the nearest parts may increase in one ratio, whilst the distances between other parts will increase in another ratio, and by changing the magnets, or the shapes of the iron, those ratios must necessarily be changed. —The only thing we can say respecting this decrease is, that the attractive force decreases faster than the simple ratio of the distances.*

* Such experiments are made by fastening a magnet to one arm of a balance, by placing the iron at different distances below the magnet, and by counterpoising the attraction with weights in the opposite scale of the balance.

There is a limit in the shape and weight of the iron which may be most forcibly attracted by a given magnet; viz. more forcibly than a smaller or larger, a more or less, extended piece of iron; but this limit can only be determined by actual experiments. A single piece of iron is attracted more forcibly than if it be divided into several parts, and all those parts be presented to the same magnet.

The attraction between the different poles of two magnets has been found to begin from a greater distance, but to be less powerful when in contact, than between soft iron and a magnet.

205. Magnetic repulsion takes place only between similar poles of different magnets (203), and has nearly as much force as the mutual attraction of the poles of different names. But it frequently happens, that though magnets are placed with their like poles towards each other, yet they either attract each other, or show a perfect indifference. These phenomena seem to contradict the above-mentioned general law; but the following facts will remove the difficulty:

When a piece of iron, or of any other substance that contains iron, is brought within a certain distance of a magnet, it becomes itself a magnet, having the poles, the attractive and repulsive properties, &c. like another magnet. The part of it which is nearest to the magnet, acquires a contrary polarity, and the opposite part, the same polarity.

The magnetism which is acquired by being placed within the influence of a magnet, in soft iron, lasts only whilst the iron continues in that situation, and when removed from the vicinity of the magnet, its magnetism vanishes immediately. But the case is quite different with hard iron, and especially with hard steel; for the harder the iron or the steel is, the more permanent is the magnetism which it acquires from the influence of

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a magnet; but it will be in the same proportion more difficult to render it magnetic.

206. From those facts three consequences are evidently deduced, viz. 1st, that there is no magnetic attraction but between the contrary poles of magnets; for the iron or other ferruginous body, which is presented to the magnet, must itself become a magnet before it is attracted; 2dly, it appears why a magnet attracts a piece of soft iron more forcibly than hard iron, and much more than hard steel; viz. because the latter does not become so strongly or so easily magnetic as the soft iron when presented to a magnet; and 3dly, that no magnetic repulsion can take place but between poles of the same name; for when the north pole, for instance, of one magnet does not seem to attract or repel, or it actually attracts what was called the north pole of the other magnet; the fact is, either that the two north, or the two south poles have destroyed each other; or that the superior force of one of the magnets has actually changed the poles of the weaker magnet; as is, beyond a doubt, proved by experiments.

207. Neither the magnetic attraction nor the magnetic repulsion is in the least diminished or otherwise affected by the interposition of any sort of bodies, except iron, or such bodies as contain iron.

The properties of the magnet are not affected either by the presence or by the absence of air.

Heat weakens the power of a magnet, and the subsequent refrigeration restores it, but not quite to its pristine degree. A white heat destroys it entirely or very nearly so; hence it appears, that the powers of magnets must be varying continually. Iron in a full red heat or white heat, (as I found by means of very decisive experiments) is not attracted by the magnet; but the attraction begins to act as soon as the redness begins to disappear.*

The attractive power of a magnet may be increased considerably by gradually adding more and more weight to it; keeping it at the same time in a proper situation, viz. with its north pole towards the north, &c. And on the contrary, that power may be diminished by an improper situation, and by keeping too small a piece of iron, or no iron at all, appended to it.

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* See my Treatise on Magnetism, 3d edition, Part IV. Chap. IV. for further particulars relative to it.

It seems that in the northern parts of the world, the north pole of a magnet has more power than its south pole, whereas the contrary effect has been said to take place in the southern parts of the world.

Amongst the natural magnets, the smallest generally possess a greater attractive power in proportion to their size than those of a larger size. I have seen a small magnet that weighed about six or seven grains, and which could lift a weight of about 300 grains. Magnets of above two pounds weight seldom lift up ten times their own weight of iron.

It frequently happens, that a natural magnet, cut off from a larger loadstone, will be able to lift a greater weight of iron than the original loadstone itself. This must be attributed to the heterogeneous nature of the original loadstone, of which the part cut off may be the purest.

208. As both magnetic poles together attract a much greater weight than a single pole, and as the two poles of a magnet generally are in opposite parts of its surface, in which case it is almost impossible to adapt the same piece of iron to them both at the same time; therefore it has been commonly practised to adapt two broad pieces of soft iron to the poles of the stone, and to let them project on one side of the stone; for those pieces become themselves magnetic while thus situated, and to them the piece of iron or weight may be easily adapted. Those two pieces of iron are generally fastened upon the stone by means of a brass or silver box. The magnet in this case is said to be *armed*, and the two pieces of iron are called the *armature*.

Fig. 91. represents an armed magnet, where AB is the loadstone, CD, CD, are the armature, or the two pieces of soft iron, to the projections of which DD the iron weight F is to be applied. The dots ECDCD represent the brass box with a ring at E, by which the armed magnet may be suspended.

Artificial magnets, when straight, are sometimes armed in the same manner; but they are frequently made in the shape of a horse-shoe, having their poles at the truncated extremities, in which shape they want no armature.

209. It has been said above, that the magnet attracts iron only, or such bodies as contain iron; and as iron is universally dispersed

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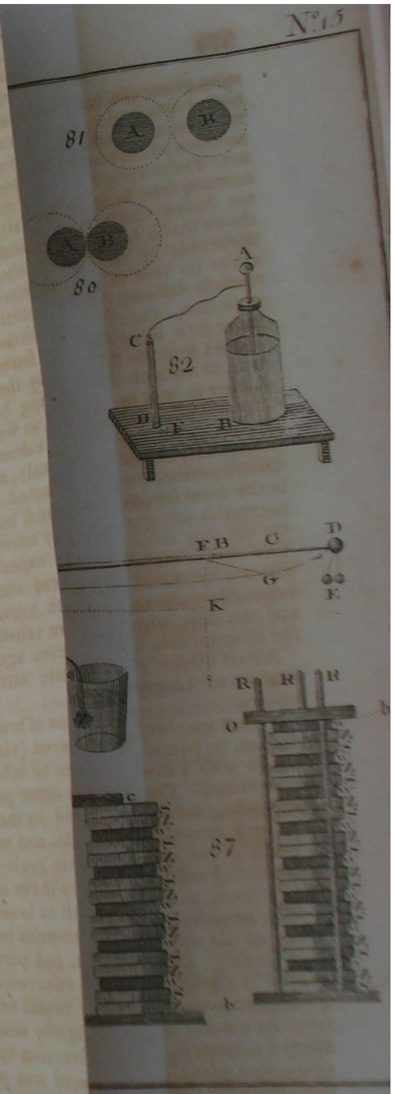
throughout the natural bodies, it is evident that a vast number of bodies must on that account be attracted by the magnet more or less forcibly. Indeed it is wonderful to observe what a small admixture of iron will render a body sensibly attractible by the magnet. Yet it must be acknowledged, that though every body which contains iron is in some measure attracted by the magnet, it does not follow that no other body can be attracted by it. Experience shows that a vast number of substances are in a very slight degree attractible by the magnet, and those substances seem to contain either no iron at all, or an exceedingly small quantity of it, extremely diffused and oxidated. To manifest this small degree of attraction, the substances must be placed upon a piece of paper or a light shaving of cork, to float upon water, and a strong magnet must be gently approached, sideways, within sometimes a tenth of an inch distance from the substance under trial. In this manner it will be found that the following substances are in some measure affected by the magnet; viz. most metallic ores, especially after their having been exposed to a fire. Zinc, bismuth, and particularly cobalt, as well as their ores, are almost always attracted. Of the earths, the calcareous is the least, if at all, and the siliceous is the most frequently, attracted. The ruby, the chrysolite, and the tourmalin are attracted. The emerald, and particularly the garnet, are not only attracted, but frequently acquire a permanent polarity. The opal is weakly attracted. Amber and other combustible minerals are attracted, especially after combustion. Most animal and vegetable substances after combustion are attracted. Even soot, and the dust which usually falls upon whatever is left exposed to the atmosphere, are sensibly attracted by the magnet.

About fifteen years ago, I discovered several remarkable facts relative to magnetic attraction; the principal of which are as follows:

If most specimens of brass, which show no attraction towards the magnet, be hammered (viz. be hardened by being beat with a hammer or with a stone or otherwise), they will in that hardened state be attracted. The same piece of brass will no longer be attracted after being softened in the fire; a second hammering will again render it attractible, and so on repeatedly.

Most of the native grains of platina have the same property, viz. hammering renders them attractible by the magnet; and heat deprives them, as well as brass, of that property.

The attraction between iron and the magnet, is increased by the action of the nitric, and particularly of the sulphuric acid upon the iron, during the effervescence. For this purpose the iron was placed in a proper vessel near one end of a magnetic needle, (viz. a magnetic bar lightly suspended) which was a little deflected from its natural direction by the proximity of the iron; but when diluted sulphuric acid was poured upon the iron, and the effervescence took place, the magnetic needle moved a little towards the iron, showing that the attraction was increased by the action of the



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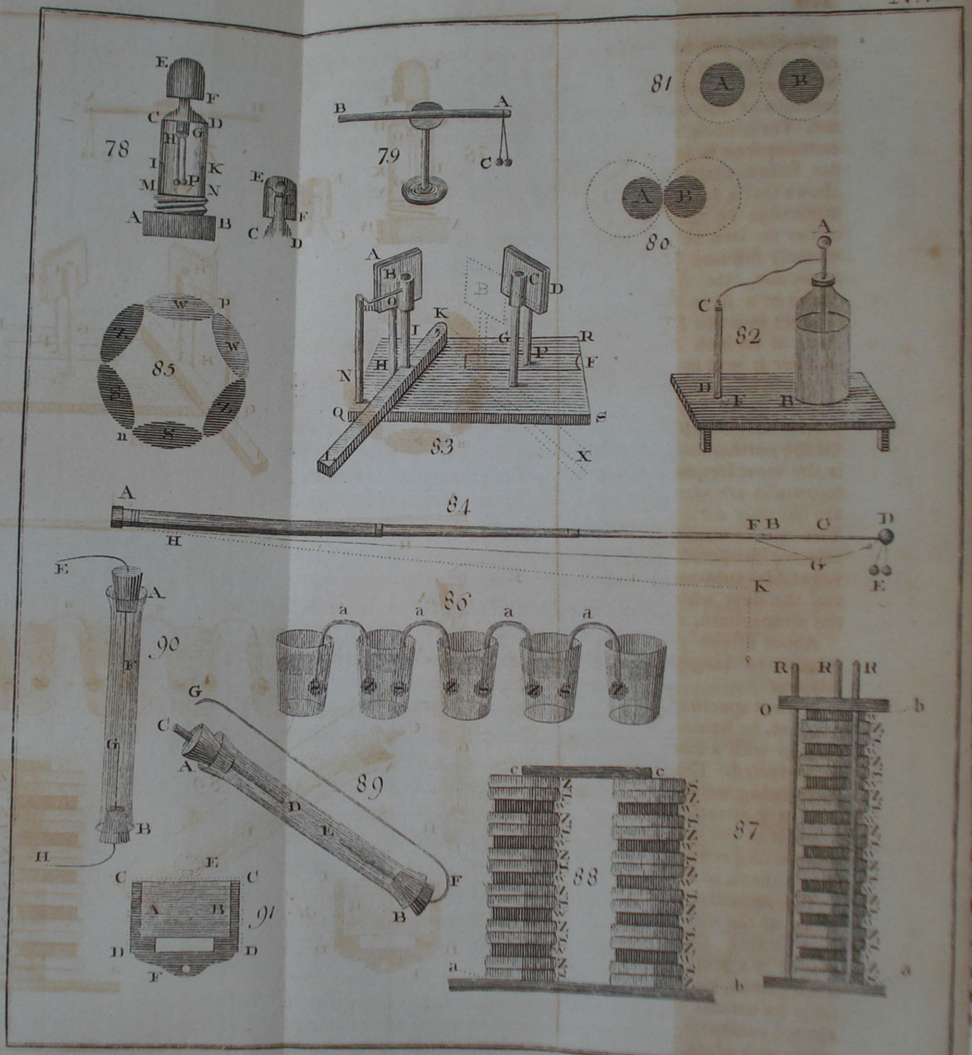

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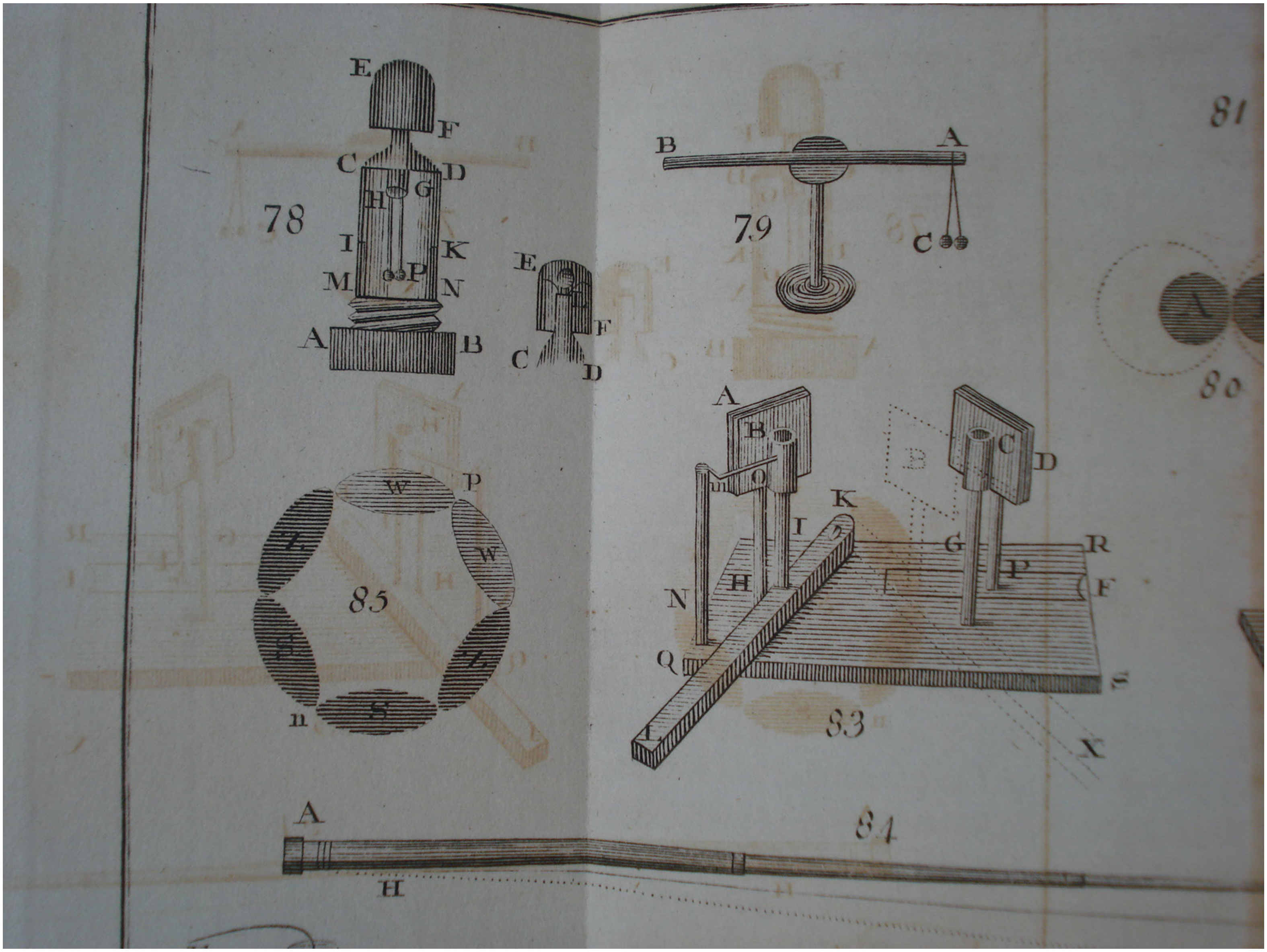

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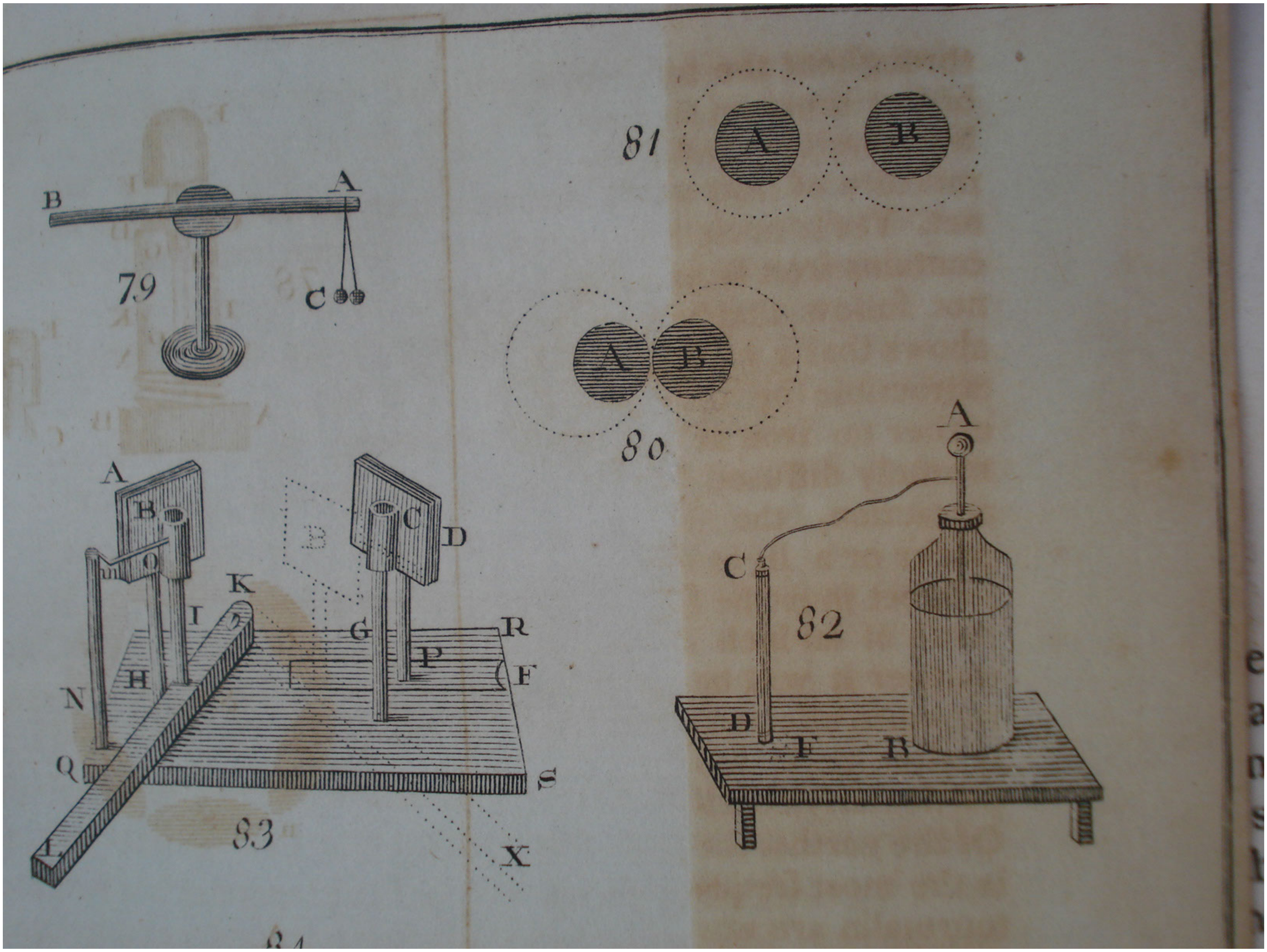

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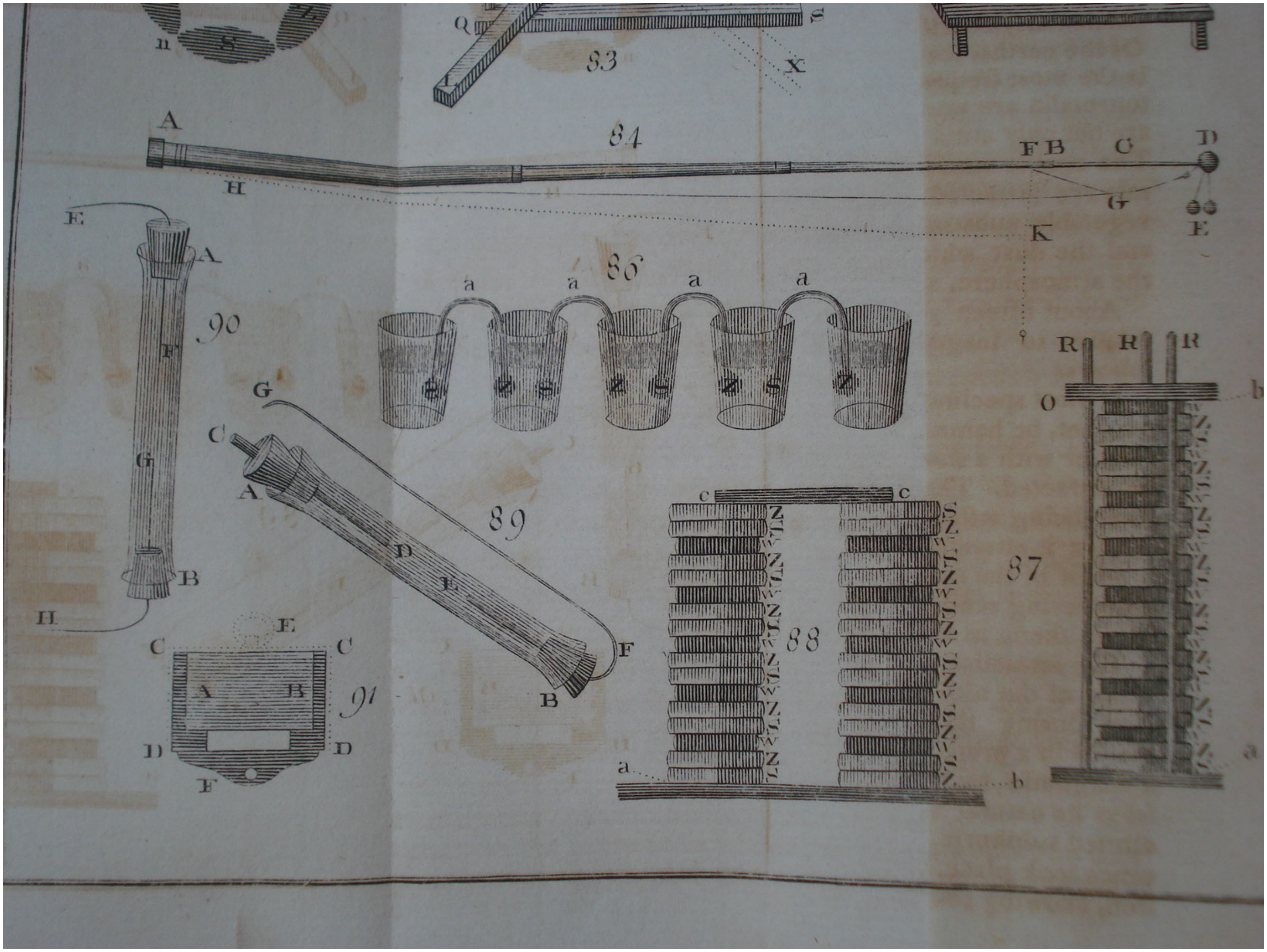

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acid. The nitric acid produced the like effect, but not so powerfully. When the effervescence was nearly finished, the needle was found to stand further from the iron than it did before the acid was poured upon the iron; which was certainly owing to the iron remaining in an oxigenated state.

CHAPTER III.

Of the Magnet's directive Property, or Polarity.

210. NO magnet is without a south and a north pole; but it frequently happens that the same magnet has more than two poles; viz. two or more north poles, and as many, or at least as many, and one more or less, south poles, on different parts of its surface; and this principally arises from the irregular shape of the magnet.

Those various poles are ascertained by presenting the various parts of the surface of the magnet in question to a given pole (for instance, the north) of a slender magnet lightly suspended, and observing which parts attract it and which repel it; for the latter must be north poles, and the former, south poles.

It sometimes happens, though not frequently, that two poles of the same name, and equally powerful, are at the opposite extremities of a magnet, and a pole of the other name lies in the middle, in which case the magnet has no tendency to place itself in the magnetic meridian. But good magnets, of a uniform texture and shape, have two poles only, which lie at opposite parts of their surfaces; so that a line drawn from one to the other, passes through the centre of the magnet.* That

* Here it must not be understood, that the polarity of a magnet resides only in two points of its surface; for, in truth, it is the half, or a great part of the magnet, that is possessed of one polarity,

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line is called the *axis*, and a line formed all round the surface of the magnet, by a plane which divides the axis into two equal parts, and is perpendicular to it, is called *the equator of the magnet*. Thus philosophers have appropriated to the magnets, the poles, the equator, as also the meridians of the earth; but, to complete the similarity, magnets have often been made of a spherical shape, with the poles, the equator, the meridians, &c. marked upon their surfaces. When thus shaped, they have been called *terrellas*, that is, *small earths*.

211. When a magnet having two poles is freely suspended, or if it be placed to float upon water, and no iron be near, it will place itself in the magnetic meridian, (203). This wonderful property forms the most useful part of the subject of magnetism. It is this property that enables the mariners to conduct their vessels through vast oceans, out of the sight of land, in any given direction; this directive property guides the miners in their subterranean excavations, and the traveller through deserts otherwise impassable.

The general method is to keep a magnet, be it artificial or natural, freely suspended, which in that case will place itself very nearly north and south; then the navigator, by looking at the direction of this magnet, may steer his course in any required direction.

An artificial steel magnet, fitted for this purpose in a proper box, is called the *magnetic needle*, or the *mariner's compass*, or *sea compass*, or simply the *compass*.*

212. The declination of the magnetic needle (203) is

(viz. has the property of repelling the like pole of another magnet) and the rest of the magnet is possessed of the other polarity; the poles then are those points in which that power is the strongest.

* It is not precisely known, when and by whom this wonderful property of the magnet was discovered. The most probable accounts seem to prove that this directive property of the magnet was known early in the 13th century; and that the person who first made mariners' compasses, at least in Europe, was a Neapolitan of the name of Flavio, or John de Gioja, or Giova, or Gira, who likewise lived in the 13th century.

different in different places on land, as well as at sea; and is, besides, continually varying in the same place.* For instance, the declination in London is not the same as at Paris, or as in India; and the declination in London, or in any other place, at this time, is not the same as it was some years ago. The change, or the *variation* of the declination may be observed even in one or two hours time; or more properly speaking, the magnetic meridian in any one part of the world is continually shifting its situation.† This is not owing to the various construction of the magnetic needle; for in the same place and time all good magnetic needles are directed in the same way.

The declination and the variation of the declination in different parts of the world is so uncertain as not to be foretold; an actual trial is the only method of ascertaining it. This therefore forms a great impediment to the perfection of navigation. It is true that navigators and other observers endeavour to ascertain the declination in various parts of the world, and such declinations are set down upon maps, charts, in books, &c. but on account of the continual variation, they can only serve for a few years;‡ nor has it yet been discovered that this variation or fluctuation is subject to any law or period, though various hypotheses have been offered to the public.

* This declination is said to be *east* or *west*, according as the north pole of the magnetic needle is eastward or westward of the astronomical meridian of a place.

† This variation of the declination was discovered by Columbus, in his first voyage to America in the year 1492.

‡ The best charts of magnetic declination, are a chart by Dr. Halley, which was formed upon the observations made in the beginning of the last century, and a chart formed by Messieurs Mountaine and Dodson, which contains the observations made in the year 1756. In those charts the observations are marked by means of dots, and a line is drawn through all the dots, which indicate the same declination; but it is continued further by conjecture or guess; thus various lines are drawn indicating the various declinations. The line of places, whereupon the magnetic needle points due north and south, is called *the line*

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The following Table contains the declination of the magnetic needle observed in London in different years.

Years.			
1576	11°	15′	East Declination.
1580	11	11	
16 2	6	10	
1622	6	0	
16 3	4	5	
1634	4	5	
1657	0	0	
1665	1	22½	West Declination.
1666	1	35½	
1672	2	30	
1683	4	30	
1692	6	0	
1700	8	0	
1717	10	42	
1724	11	45	
1725	11	56	
1730	13	00	
1735	14	16	
1740	15	40	
1745	16	53	
1750	17	54	
1760	19	12	
1765	20	0	
1770	20	35	
1774	21	3	
1775	21	30	
1780	22	10	
1785	22	50	
1790	23	34	
1795	23	52	
1800	24	7	

From this table it appears, that the annual variation is by no means regular, and such is likewise the case with the daily or hourly variation; which, though evidently influenced by heat and cold, does not however follow any known law.

The first of the following tables contains a specimen of hourly variation, as observed by the late ingenious Mr. Canton, F. R. S. The second shows the mean variation for each month in the year, as deduced from the same Mr. Canton's numerous observations.*

of no declination. It is observable that those declination lines, though in some places very crooked, never cross each other.

* Before volcanic eruptions and earthquakes, the magnetic nee-

The Declination observed at different Hours of the same Day, viz. June the 27th, 1759.

	Hours.	Minutes.	Declin. West.		Deg. of Fahren. Therm.
Morning	0	18	19°	2′	62
	6	4	18	58	62
	8	30	18	55	65
	9	2	18	54	67
	10	20	18	57	69
	11	40	19	4	68½
Afternoon	0	50	19	9	70
	1	38	19	8	70
	3	10	19	8	68
	7	20	18	59	61
	9	12	19	6	59
	11	40	18	51	57½

The mean Variation for each Month in the Year.

January	7′	8″
February	8	58
March	11	17
April	12	26
May	13	0
June	13	21
July	13	14
August	12	19
September	11	43
October	10	36
November	8	9
December	6	58

dle is often subject to very extraordinary movements. It is likewise agitated before and after the appearance of the northern lights: its declination on those occasions is, about noon, greater than usual.

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a fixed distance from them, the inclination of the needle, as well as its declination would remain unalterable; hence, from observing the direction of the magnetic needle in any particular place, the latitude and longitude of that place might be ascertained; but the case is far different; for the magnetic poles of the earth do not coincide with its real poles; they neither are equidistant from them; and in fact they are continually shifting their places; hence the magnetic needle changes continually and irregularly, not only its horizontal direction, but likewise its inclination, according as it is removed from one place to another, as also whilst it remains in the very same place. However, the change of dip or of inclination in the same place is very trifling. In London about the year 1576, the north pole of the dipping needle stood 71° 50′ below the horizon, and in the year 1775 it stood at 72° 3′; the whole change of inclination during so many years amounting to less than a quarter of a degree, allowing the accuracy of the observations.

CHAPTER V.

Of communicated Magnetism.

216. IT has been already mentioned (205), that when a ferruginous body comes within a certain distance of a magnet, it becomes itself a magnet; also that this magnetism is more easily communicated, but at the same time more easily lost by soft iron than by steel. Hence it appears that the best method of making artificial magnets, consists in applying one or more powerful magnets to pieces of the hardest steel, because those pieces will thereby acquire a considerable magnetic power, and will retain it for a very long time. In this operation care must be had to apply the north pole of the magnet or magnets to that extremity of the piece of steel which is required to be made the south pole, and to apply the south pole of the magnet to the opposite extremity of the piece of steel. In the same manner a weak magnet may be rendered more powerful by the application of stronger magnets, or its power may be restored when lost.—A magnet, by communicating magnetism to other

bodies, has its own power rather increased than diminished.—There are several methods of performing this operation; we shall describe the best presently; but let us previously take notice of what is commonly called the method of magnetizing steel without any magnet.*

217. Take a straight bar of soft iron (one of two or three feet in length, and about three quarters of an inch in diameter, or a common iron kitchen poker, will answer perfectly well), and, in the northern parts of the world, if you keep it in a vertical position, viz. with one end towards the ground, and with the other end upwards, you will find that the bar in that situation is magnetic; the lower extremity being a north pole (capable of attracting the south pole of a magnetic needle, and of repelling its north pole) and the upper extremity being a south pole.—If you invert the bar, its polarity will be instantly reversed.†

The explanation of this curious phenomenon is easily deduced from the preceding laws; for since in the northern parts the earth is possessed of a south polarity, the lowest part of the iron bar, by being nearest to it, must acquire the contrary, viz. the north polarity; the other extremity of the bar becoming of course a south pole. It follows likewise (and it is confirmed by actual experiments); 1st, that in the southern parts of the earth the lowest part of the iron bar acquires the south polarity; 2dly, that on the equator the iron bar must be kept horizontal, in order that it may acquire magnetism from the earth; and 3dly, that in these parts of the earth the most advantageous situation of the bar is not the perpendicular, but a little inclined to the horizon. In short, in every part of the world the iron bar must be placed in

* Strictly speaking, this method does not exist; for there is no magnetism communicated but by the action of another magnet; and in the above-mentioned method the magnetic power is originally communicated from the earth, which is a real magnet.

† An iron bar of four or five feet in length, and above an inch thick, when placed in this situation, will be capable of attracting a small bit of iron, or a small common sewing needle.

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the magnetical line; viz. in the direction of the dipping needle.

A bar of hard iron, or of steel, will not answer for the above described experiment, the magnetism of the earth not being powerful enough to magnetize it.

After this experiment it will be easily understood that permanent magnetism may be communicated in a variety of ways. Thus bars of iron which have stood long in a pretty favourable direction, viz. either north and south, or perpendicular, &c. generally acquire a permanent magnetism, for the continual action of the earth's magnetism daily communicates more and more power to it, at the same time that the iron, especially if it be not very soft, grows rather harder by rusting, or working, &c.

If an oblong piece of pretty hard iron be made red hot, and then be left to cool in the magnetical line, it will thereby acquire a degree of permanent magnetism.

If an iron bar, whilst standing in the magnetical line, be struck forcibly and repeatedly with a hammer on one of its ends, it frequently acquires permanent magnetism from it. In short, whatever seems to render the iron or the steel more susceptible of magnetism (be it heat, or vibration, or friction), if administered whilst the iron or steel is in the proper direction, is likely to fix the magnetism in it; hence an electric shock, or a stroke of lightning, or drilling, hammering, &c. frequently magnetizes the tools themselves, or other pieces of iron and steel concerned.

218. When a magnet is applied with one of its poles to one extremity of a pretty long steel bar, the latter will thereby acquire a permanent degree of magnetism; but it will be found to have several poles, viz. the end which has touched the magnet will be found possessed of the contrary polarity (say, for instance, north); a little further on, it will be found possessed of the south polarity; some way beyond that you will find another north polarity, and so forth alternately. But if the bar be not very long, then it will be found possessed of two poles only,

viz. a north pole at one end, and a south pole at the other; which shows that there is a limit in the length of the bar, which renders it the most eligible for an artificial magnet.

A magnet cannot communicate a degree of magnetism stronger than that which itself possesses; but two or more magnets joined together may communicate a greater power to a piece of steel, than either of them possesses singly: hence we have a method of constructing very powerful magnets, by first constructing several weak magnets, and then joining them together, to form a compound magnet; and to act with great power upon a piece of steel.

Mr. Canton's process for constructing magnetical bars, the rationale of which may be easily deduced from the preceding particulars, is as follows:

Let six bars be made of soft steel, about 3 inches long, $\frac{1}{4}$ inch broad, and $\frac{1}{20}$ inch thick. Let also six other steel bars be made quite hard, and about 3 inches long, $\frac{1}{2}$ inch broad, and $\frac{1}{8}$ inch thick. Each of those sets of bars must have two pieces of soft iron called *supports* or *conductors*, both equal to one bar of the respective set. One end of each of these 12 bars must be marked with a line, which end is to become the north pole. Have ready also an iron poker and tongs that have been long in use.

Place the poker nearly upright, or rather in the magnetical line, with its point downwards; and let one of the soft steel bars be tied, by means of a thread, to the middle of it, and with the marked end downwards; then with the lower end of the tongs held also in an upright position, or in the magnetical line, stroke the steel bar from the marked end upwards, about 10 times, on both sides, which will give it power enough to keep suspended a small key. Thus communicate the magnetism to four of the small bars.

This done, lay the two other small bars on a table parallel to each other, about a quarter of an inch asunder, and between their iron conductors AB, CD, fig. 93., taking care to place the marked end of one of the bars on one side, and the marked end of the other bar on the opposite side. Now place the four bars, already made magnetic, in the form shown in fig. 94., viz. two with their north poles downwards, and the other two with their south poles downwards. The two of each pair must be placed breadth to breadth, and the two pairs being put contiguous to each other at top, must be kept open at a small angle by the interposition of some hard substance I. This sort of compound magnet, formed of the four bars, must be placed with its aperture on the middle of one of the soft bars AC, taking care to let the south poles H be towards the

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marked end of the bar AC, and the north poles F towards the other extremity. In this position, the compound magnet must be slid from end to end of the said bar, viz. when the poles H are arrived at C, move the compound magnet backwards the other way, till the poles F come to A, &c. Thus stroke the lying bar four times, ending at the middle; from whence take up the compound magnet, and remove it to the middle of the other lying bar BD, taking care, as above, to let the south poles be towards the marked end of the bar; rub this in the like manner; then turn the bars AC, BD, with the sides that stood towards the table, upwards, and repeat the operation on those other sides. This being done, take up the two bars AC, BD, and let them form the inner two of the compound magnets; and place those which were before the two outside ones, between the pieces of iron or conductors, and rub them with the compound magnet formed out of the other four bars, in the same manner as before. This operation must be repeated till each of the six bars has been rubbed four or five times, by which means they will acquire a considerable degree of magnetic power.

When the small bars have been thus rendered magnetic, in order to communicate the magnetism to the large bars, lay two of them upon the table, between their two conductors, or pieces of iron, in the same manner, and with the same precautions, as were used for the small bars; then form a compound magnet with the six small bars, placing three of them with the north poles downwards, and the three others with their south poles downwards. Place those two parcels at an angle, as was done with four of them, the north extremity of one parcel being put contiguous to the south extremity of the other; and with this compound magnet, stroke four of the large bars, one after the other, about 20 times on each side, by which means they will acquire some magnetic power.

When the four large bars have been so far rendered magnetic, the small bars are laid aside, and the large ones are strengthened by themselves, in the same manner as was done with the small bars.

With some sort of steel, a few strokes are sufficient to impart to them all the power they are capable of retaining; other sorts require a longer operation; and sometimes it is impossible to give them more than just a sensible degree of magnetism.

In order to expedite the operation, the bars ought to be fixed in a groove, or between brass pins; otherwise the attraction and friction between the bars will be continually deranging them, when placed between the conductors.

A set of such bars are exceedingly useful for magnetizing other bars, or needles of compasses, &c.; their power may also be increased when lost or impaired by mismanagement, &c. A set of such bars, viz. six bars and the two iron conductors, may be preserved in a box; taking care to place the north pole of one contiguous to the south pole of the next, and that contiguous to the north pole of the third, &c.

It may perhaps be necessary to say also something concerning the communication of magnetism to crooked bars like ABC, fig. 95.

Place the crooked bar flat upon a table, and to its extremities apply the magnetic bar DF, EG; joining their extremities F, G, with the conductor or piece of soft iron FG: then to its middle apply the magnetic bars placed at an angle, as in Canton's method, or you may use two bars only, placed as shown in the figure, and stroke the crooked bar with them from end to end, following the direction of that bent bar; so that on one side of it the magnetic bars may stand in the direction of the dotted representation LK. In this manner, when the piece of steel ABC has been rubbed a sufficient number of times on one side, it must be turned with the other side upwards, &c.

It is evident, that the magnets DF, EG, as also the magnets H, I, must be placed so that their south poles be towards that extremity of the crooked steel, which is required to be made the north pole, &c.

CHAPTER VI.

Theory of Magnetism.

219. IN the present chapter we shall briefly take notice, 1st, Of the principal phenomena of the earth's magnetism; and 2dly, Of the supposed magnetic fluid.

That the earth acts as a great magnet is so clearly indicated by a variety of facts and considerations, that at present it is hardly possible to doubt of it. In the first place the directive property of the magnetic needle on the surface of the earth is so analogous to that of a small needle upon the surface of a common magnet or terrella, as to strike every observer. 2dly, The magnetism which iron acquires by its position, is another striking indication of the earth's magnetism. 3dly, The vast masses of iron, in various states, which are to be found almost every where in the bowels of the earth, and which are frequently magnetic, prove beyond a doubt that the earth is a vast but irregular magnet, and that its mag-

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netism arises from the magnetism of all the ferruginous bodies that are contained in it; so that the magnetic poles of the earth must be considered as the centres or collected powers of all those magnetic ferruginous substances. It follows likewise that according as those masses of iron are affected by heat and cold, by decomposition, by mixture with other substances, by volcanoes, by earthquakes, or mechanical derangements, &c. so the magnetic poles of the earth must shift their situation; and this is the cause of the variation of the magnetic needle.*

The above-mentioned causes are sufficient to account for the daily, or hourly, or yearly variations, though it is not and perhaps it will never be in our power to determine what part of the effect is due to each of those causes, or what is the precise result of the whole. It is therefore needless to suppose, according to some philosophers, that a large movable magnet is contained within the earth, or to admit other hypotheses still less probable.

220. Human ingenuity has contrived abundance of hypotheses in explanation of the wonderful phenomena of magnetism; but the insufficiency of most of them renders it useless to state them in this work, excepting however one which was proposed by Aepinus, and which is similar to the Franklinian theory of Electricity.

There are undoubtedly several strong points of analogy between magnetism and electricity; such as the analogy between the two poles of a magnet and the two electricities; the attraction which takes place between magnetic poles of different denominations analogous to the attraction between bodies differently electrified, &c. Now Aepinus is led to imagine, that there exists a fluid productive of all the magnetic phenomena, and consequently to be called *the magnetic fluid;* that this fluid is so very subtile as to penetrate the pores of all bodies;

* See the late Dr. Lorimer's attempt to explain the cause of the variation of the Magnetic Needle in my Treatise on Magnetism, 3d edition.

and that it is of an elastic nature, viz. that its particles are repulsive of each other.

He further supposes, that there is a mutual attraction between the magnetic fluid and iron, or other ferruginous bodies; but that no other substance has any action upon this fluid. He then observes, that there is a great deal of resemblance between ferruginous bodies and electrics, or nonconductors of electricity; for the magnetic fluid passes with difficulty through the pores of the former, as well as the electric fluid passes with difficulty through the pores of the latter.

According to this hypothesis, iron, and all ferruginous substances, contain a quantity of magnetic fluid, which is equably dispersed through their substance, when those bodies are not magnetic; in which state they show no attraction or repulsion, because the repulsion between the particles of the magnetic fluid is balanced by the attraction between the matter of those bodies and the said fluid, in which case those bodies are said to be in a natural state. But when in a ferruginous body, the quantity of magnetic fluid belonging to it, is driven to one end, then the body becomes magnetic, one extremity of it being now overcharged with magnetic fluid, and the other extremity undercharged. Bodies thus constituted, viz. rendered magnetic, exert a repulsion between their overcharged extremities, in virtue of the repulsion between the particles of that excess of magnetic fluid, which is more than sufficient to balance, or to saturate, the attraction of their matter. There is an attraction exerted between the overcharged extremity of one magnetic body, and the undercharged extremity of the other, on account of the attraction between the magnetic fluid and the matter of the body; but, to explain the repulsion which takes place between their undercharged extremities, we must either imagine that the particles of ferruginous bodies when deprived of the magnetic fluid, must be repulsive of each other, or that the undercharged extremities *appear* to repel each other, only because either of them attracts the opposite over-

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charged extremity; both which suppositions are embarrassed with difficulties.

A ferruginous body, according to this hypothesis, is rendered magnetic by having the equable diffusion of the magnetic fluid disturbed throughout its substance; so as to have an overplus of it in one or more parts, and a deficiency of it in one or more other parts: and it remains magnetic as long as its impermeability prevents the restoration of the equable diffusion of fluid, or of the balance between the overcharged and the undercharged parts. Moreover, the piece of iron is rendered magnetic by the action of a magnet, because, when the overcharged part or pole of the magnet is presented to it, the overplus of magnetic fluid in that pole repels the magnetic fluid away from the nearest extremity of the iron, (which therefore becomes undercharged) to a more remote part of the iron which becomes overcharged. If the iron be magnetized by the contact of the undercharged side of the magnet, then the matter of the latter attracts the magnetic fluid of the iron to that extremity of the iron which lies nearest to itself.

In a similar manner you may explain the action of two magnets upon each other.

The magnet has not been found to have any action whatever upon the human body, and of course the idle stories of its being beneficial to persons afflicted with the toothach, or with white swellings, or to parturient women; as also of the wounds inflicted with a magnetized knife being mortal, more than if the knife had not been magnetic, have not the least foundation in truth or experience. The barefaced imposition which has for several years been practised under the name of *animal magnetism*, is another absurdity.

In the *Reichsanzeiger*, a German periodical publication, No. CCXXII. for 1797, it is said, that a certain person having an artificial magnet suspended from the wall of his study, with a piece of iron adhering to it, remarked, for several years, that the flies in the room, though they frequently placed themselves on other iron articles, never settled upon the artificial magnet.

CHAPTER VII.

The Construction and the Use of the principal Magnetical Instruments, as also the Description of Experiments useful for the Illustration of the subject.

221. THE magnetical instruments may be reduced to three principal heads; viz. 1st, the magnets or magnetic bars, which are necessary to magnetize needles of compasses, or such pieces of steel, iron, &c. as may be necessary for various experiments; and which have been explained; 2dly, the compasses, such as are used in navigation, and for other purposes, which are only magnetic needles nimbly suspended in boxes, and which, according to the purposes for which they are particularly employed, have several appendages, or differ in size, and in accuracy of divisions, &c. whence they derive the different names of pocket compasses, steering compasses, variation compasses, and azimuth compasses; and 3dly, the dipping needle.*

222. The magnetic needles, which are commonly used at sea, are between four and six inches long; but those which are used for observing the daily variation, are made a little longer, and their extremities point the variation upon an arc or circle properly divided and affixed to the box.†

The best shape of a magnetic needle is represented in fig. 96 and 97; the first of which shows the upper side, and the second shows a lateral view of the needle, which is of steel, having a pretty large hole in the mid-

* A curious contrivance, which is at once a dipping and a variation needle, was some years ago made by the late Dr. Lorimer. See a description of it in the Phil. Trans. vol. 65. or in my Treatise on Magnetism.

† See the description of my new variation compass in my Treatise on Magnetism.

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dle, to which a conical piece of agate is adapted by means of a brass piece O, into which the *agate cap* (as it is called) is fastened. Then the apex of this hollow cap rests upon the point of a pin F, which is fixed in the centre of the box, and upon which the needle, properly balanced, turns very nimbly.* For common purposes, those needles have a conical perforation made in the steel itself, or in a piece of brass which is fastened in the middle of the needle.†

223. A mariner's compass, or compass generally used on board of ships, is represented by fig. 98. The box, which contains the card or fly with the needle, is made of a circular form, and either of wood, or brass, or copper. It is suspended within a square wooden box, by means of two concentric circles, called *gimbalds*, so fixed by cross axes *a*, *a*, *a*, *a*, to the two boxes, (see the plan, fig. 99.) that the inner one, or compass box, shall retain a horizontal position in all motions of the ship, whilst the outer or square box is fixed with respect to the ship. The compass box is covered with a pane of glass, in order that the motion of the card may not be disturbed by the wind. What is called the card, is a circular piece of paper, which is fastened upon the needle, and moves with it. Sometimes there is a slender rim of brass, which is fastened to the extremities of the needle, and serves to keep the card stretched. The outer edge of this card is divided into 360 equal parts or degrees, and within the circle of those divisions it is again divided into 32 equal parts, or arcs, which are called the *points of the compass*, or *rhumbs*, each of which is often subdivided into quarters. The initial letters N,

* It must be observed, that the needle which is balanced before it is magnetized, will lose its balance, by being magnetized on account of the dipping, as shown in the third chapter; therefore a small weight or movable piece of brass is placed on one side of the needle, as shown in fig. 97., by the shifting of which, either nearer to or further from the centre, the needle may always be balanced.

† The simplest magnetic needles are made of common sewing needles magnetized, and laid to swim upon water.

NE, &c. are annexed to those rhumbs, to denote the North, North East, &c. The middlemost part of the card is generally painted with a sort of star, whose rays terminate in the above-mentioned divisions.

The azimuth compass is nothing more than the above-mentioned compass, to which two sights are adapted, through which the sun is to be seen, in order to find its azimuth, and from thence to ascertain the declination of the magnetic needle at the place of observation; see fig. 100. The particulars in which it differs from the usual compass, are the sights F, G; in one of which, G, there is an oblong aperture with a perpendicular thread or wire stretched through its middle; and in the other sight F, there is a narrow perpendicular slit. The thread or wire HI is stretched from one edge of the box to the opposite. The ring AB of the gimbalds rests with its pivots on the semicircle CD, the foot E of which turns in a socket, so that whilst the box KLM is kept steady, the compass may be turned round, in order to place the sights F, G, in the direction of the sun.*

There are, on the inside of the box, two lines drawn perpendicularly along the sides of the box, just from the points where the thread HI touches the edge of the box. These lines serve to show how many degrees the north or south pole of the needle is distant from the azimuth of the sun; for which purpose, the middle of the apertures of the sights F, G, the thread HI, and the said lines, must be exactly in the same vertical plane. The use of the thread HI, which is often omitted in instruments of this sort, is likewise to show the degrees between the magnetic meridian and the azimuth, when the eye of the observer stands perpendicularly over it. On the side of the box of this sort of compasses, there generally is a nut or stop, which, when

* The pivots of the gimbalds of this, as well as of the common sort of compasses, should lie in the same plane with the point of suspension of the needle, in order to avoid as much as possible the irregularity of the vibrations.

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pushed in, bears against the card and stops it, in order that the divisions of the card which coincide with the lines in the box, may be more commodiously read off.*

224. The dipping needle, though of late much improved, is however still far from perfection. The general mode of constructing it is to pass an axis quite through the needle, to let the extremities of this axis, like those of the beam of a balance, rest upon its supports, so that the needle may move itself vertically round, and when situated in the magnetic meridian, it may place itself in the magnetic line. The degrees of inclination are shown upon a divided circle, in the centre of which the needle is suspended. Fig. 101. represents a dipping needle of the simplest construction; AB is the needle, the axis of which FE rests upon the middle of two lateral bars CD, CD, which are made fast to the frame that contains the divided circle AIBK. This machine is fixed on a stand G; but, when used at sea, it is suspended by a ring H, so as to hang perpendicularly. When the instrument is furnished with a stand, a spirit level O is generally annexed to it, and the stand has three screws, by which the instrument is situated so that the centre of motion of the needle, and the division of 90° on the lower part of the divided circle, may be exactly in the same line; perpendicular to the horizon.†

225. The few experiments which follow, are principally intended to illustrate the theory. As for entertaining magnetical experiments, they may be easily derived from the general subject which has been already explained.

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* What the azimuth of a celestial object is, and how it may be ascertained, will be shown in a subsequent part of this work.

† The greatest imperfections of this instrument are the balancing of the needle, and the difficulty of ascertaining whether the needle retains its equipoise. In making the observation of the dip at any particular place, the best method to avoid the error arising from the want of balance, is, first to observe the dip of the needle, then to reverse its magnetism, by the application of magnetic bars, so that the end of the needle, which before was elevated above the horizon, may now be below it; and lastly, to observe its dip again; for a mean of the two observations will be pretty near the truth, though the needle may not be perfectly balanced.

1. The method of discovering whether a body is attractible by the magnet or not, and whether it has any polarity or not, or which is its south, and which its north pole, is so easily performed as not to require many words; for by approaching a magnet to the body in question (which, if necessary, may be set to swim upon water,) or by presenting the body in question to either extremity of a suspended magnetic needle, the desired object may be obtained.

2. Tie two pieces of soft iron wire, each to a separate thread; join the threads at top, and forming them into a loop, suspend them so as to hang freely. Then bring the north end of a magnetic bar, just under them, and the wires will immediately repel each other, and this divergency will increase to a certain limit, according as the magnet is brought nearer, and *vice versa*. The reason of this phenomenon is that by the action of the north magnetic pole of the magnetic bar, both the lower extremities of the wires acquire the same, viz. the south polarity; consequently they repel each other; and the upper extremities acquire the north polarity, in consequence of which they also repel each other.

If instead of the north pole of the magnetic bar, you present its south pole, the repulsion will take place as before; but now the lower extremities of the wires acquire the north, and the upper extremities, the south, polarity.

On removing the magnet, the wires, if of soft iron, will soon collapse, having lost all their magnetic power; but if steel wires, or common sewing needles be used, they will continue to repel each other, after the removal of the magnet; the magnetic power being retained by steel.

3. Lay a sheet of paper flat upon a table, strew some iron filings upon the paper, place a small magnet among them; then give a few gentle knocks to the table, so as to shake the filings. The particles of iron clinging to one another immediately form themselves into lines, which at the very poles are in the same direction with the axis of the magnet, and a little sideway of the poles begin to bend, and then form complete arcs, reaching from some point in the northern half of the magnet, to some other point in the southern half. The reason of this phenomenon is not, as some persons imagine, that a current of fluid issues from one pole and enters at the other pole of the magnet; for if that were the case, the iron filings would be all driven upon one of the poles. But the true reason is, that each of the particles of iron is become actually magnetic, and possessed of the two poles, in consequence of which each particle, at the place where it happens to stand, disposes itself in the same manner as any other magnet would do; and moreover attracts with its extremities the contrary poles of other particles.

4. Take a strong magnet, and find out by trial such a piece of iron as is very little heavier than what the magnet will support. It is plain, that if you affix this iron to one pole of the magnet, the

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moment you remove your hand the iron will drop off; but if, before you remove your hand, you present another larger piece of iron to the under part of the former, and at about half an inch from it, you will then find that the magnet will be able to support the first piece of iron which it could not support before, when the secondary piece of iron stood not below it. In short, a magnet can lift a greater weight of iron from over another piece of iron, such as an anvil or the like, than from a table; the reason of which is, that in the former case, the iron basis or inferior piece of iron, becoming itself in some measure magnetic, helps to increase the magnetism of the first piece of iron, and consequently tends to increase the attraction.

5. Place a magnetic bar AB, fig. 102., so that one of its poles may project a short way beyond the table, and apply an iron weight C to it; then take another magnetic bar, DE, like the former, and bring it parallel to and just over the other, at a little distance, and with the contrary poles towards each other; in consequence of which the attraction of B will be diminished, and the iron C, if sufficiently heavy, will drop off, the magnet AB being then only able to support a smaller piece of iron. By bringing the magnets still nearer to each other, the attraction of B will be diminished still further; and, when the two magnets come quite in contact, (provided they be equal in power) the attraction between B and C will vanish entirely; but if the experiment be repeated with this difference, viz. that the homologous poles of the magnets be brought towards each other, then the attraction between B and C, instead of being diminished, will be increased.

6. Let an iron wire of about a quarter of an inch in diameter, and 4 or 5 inches long, be bent somewhat like a Gothic arc, viz. with a sharp corner in the middle, as ABC, fig. 103, and tie it fast to any proper stand, or let an assistant hold it, with the corner downwards; then apply either pole of the magnet DE to one of its extremities A, and whilst the magnet remains in that situation, apply a piece of iron H, of no great size, to the corner C, and you will find that the iron remains suspended. Now, if another magnet be applied to the other extremity B of the crooked iron, so that the pole G may be contrary to the pole E, the iron H will immediately drop off; but if the pole G be analogous to the pole E, then the iron H not only will remain adhering to C, but the said corner will be capable of supporting a weight still greater than H. The reason of which is, that in the former case the extremities A and B, of the bent iron, being possessed of different polarities, the corner C became the magnetic centre, where there is no attraction nor repulsion; whereas in the second case, both extremities of the bent iron being possessed of the same polarity, the corner C acquired the contrary polarity. In this latter case the crooked iron must have two magnetic centres, viz. one on each side.

7. In order to imitate, in some measure, natural magnets; take martial æthiops, or, which is more easily procured, reduce into very fine powder the scales of iron which fall off from the red hot iron when hammered in blacksmiths' shops: mix this powder with drying linseed oil, so as to form it into a very stiff paste, and shape it in a proper mould, into the form of a terrella or human head, &c. This done, place it in a warm place during some weeks, by which means it will become very hard; then render it magnetic by the application of powerful magnets, and it will acquire a considerable permanent power.

THE END OF PART III.

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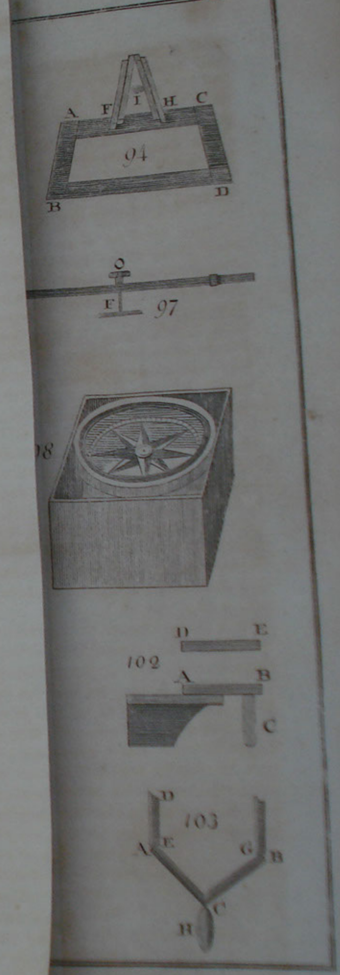

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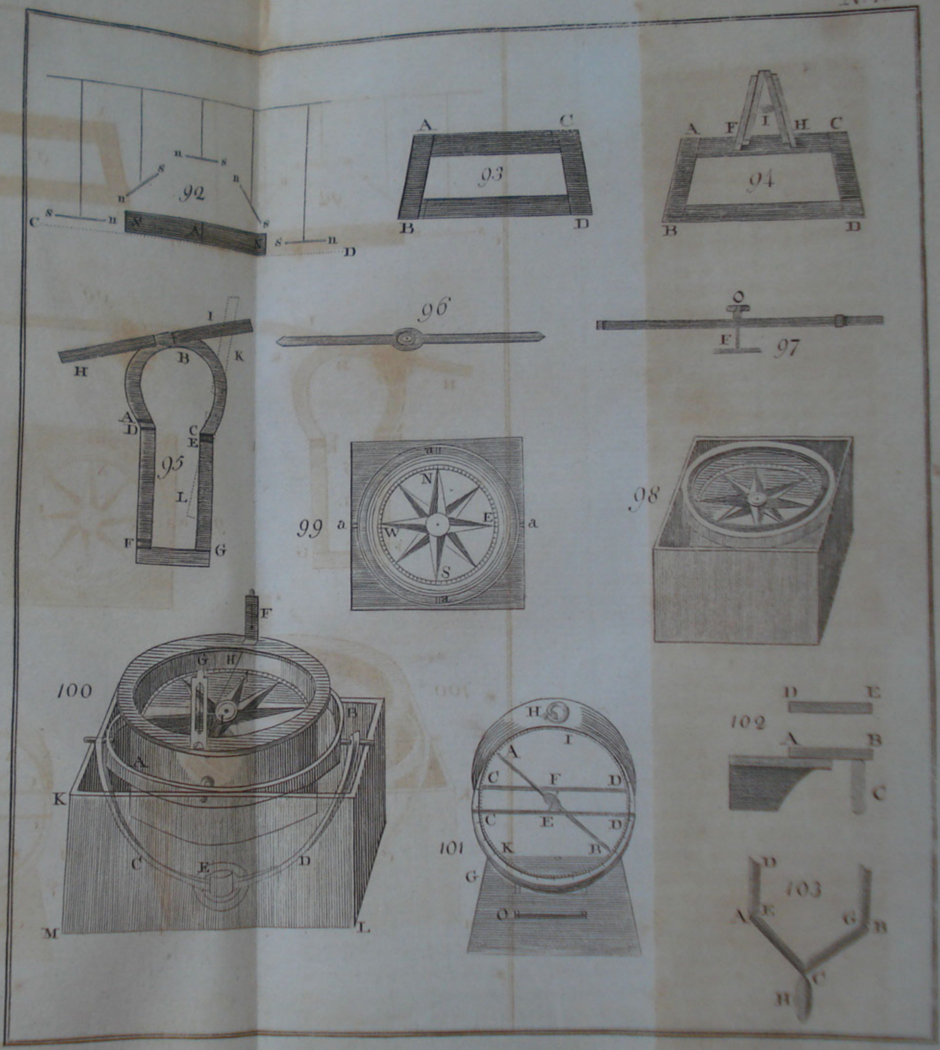

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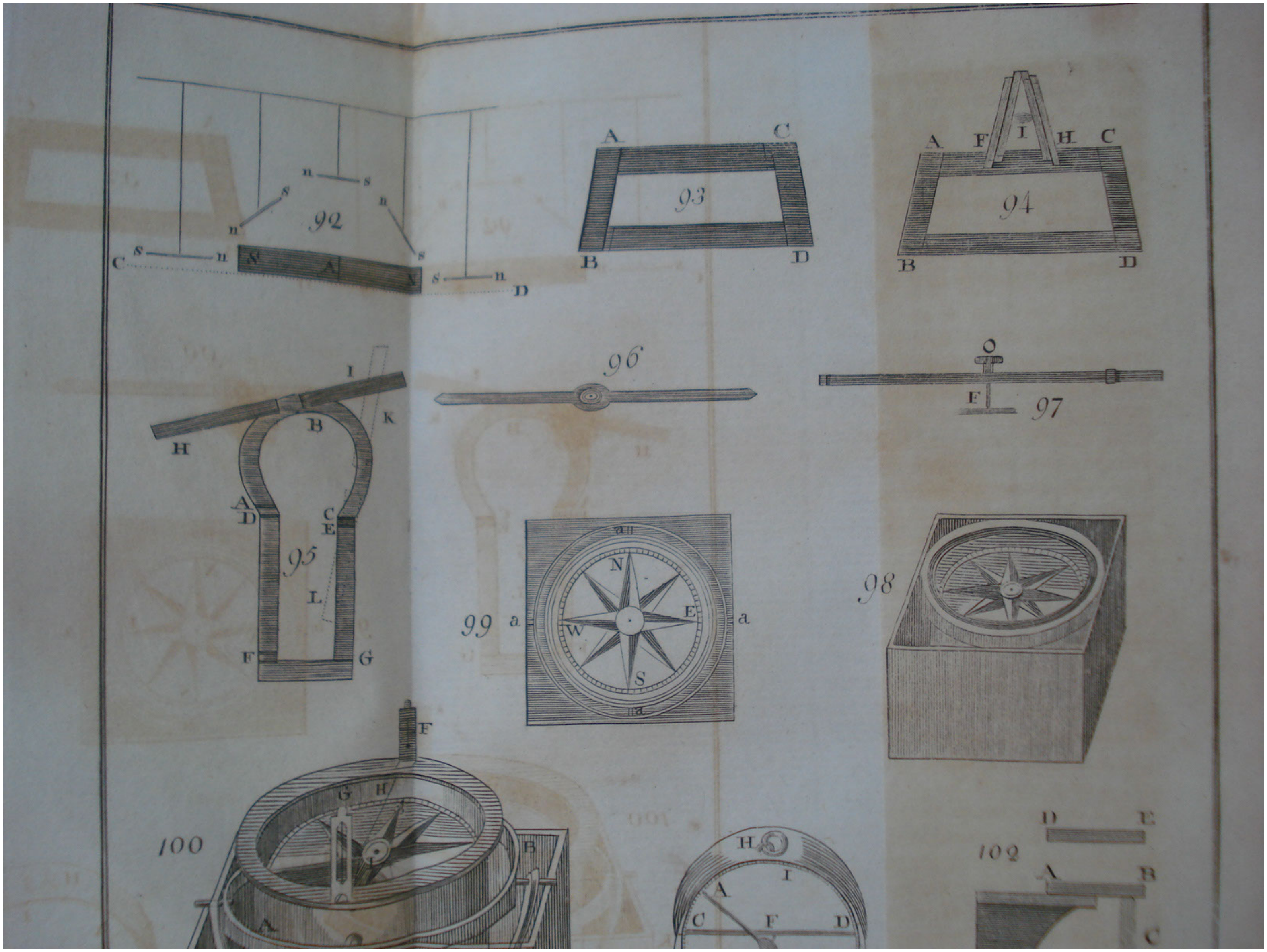

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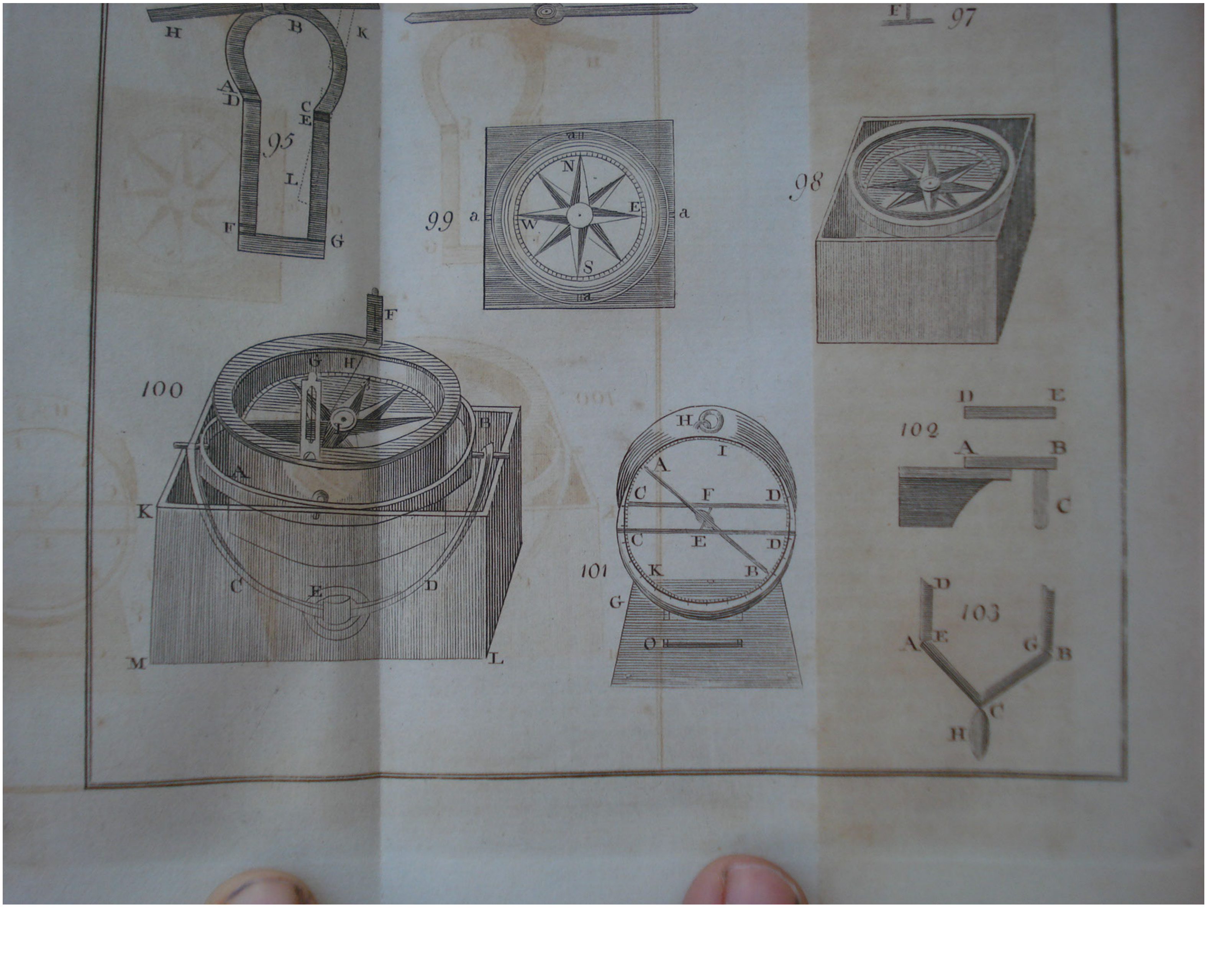

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